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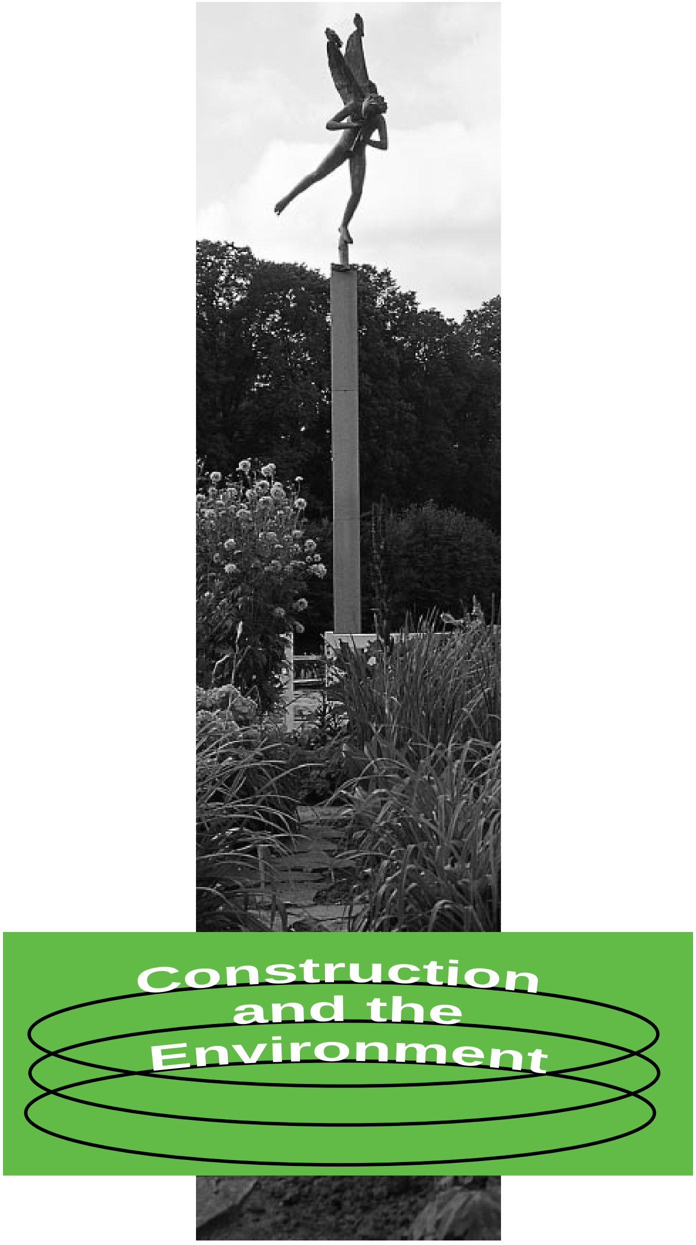

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Life Cycle Design and Ecomaterials Technology of Building Structural Composite Components for Sustainable Construction

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Abstract
Concept of life cycle design of building structural composite components (such as steel reinforced concrete (RC) and fiber reinforced plastic reinforced concrete (FRPRC)) is proposed, considering the total life cycle processes of production, in service, demolition, recycling and/or reuse, and taking in advance into account the easiness of demolition, recycling. Hybrid structural systems composed of steel reinforced concrete (RC) columns and fiber reinforced plastic reinforced concrete (FRPRC) beams, connected with steel fasteners are the recommended. Ecomaterials design and elemental technology satisfying both the long service life and the recyclability of building structural composite materials and/or components is discussed, in order to try to reduce the environmental burdens of mass of waste building materials which partly cause the dominant environmental problem, as a basis for establishment of the sustainable construction considering the harmony among the environment, economy and safety. Recyclable precast lightweight high strength concrete components reinforced with recyclable continuous fiber reinforced thermoplastic (FRTP) rebars and various effective demolition and recycling methods are considered.

The following experimental results as part of elemental technology establishing this ecomaterials design are reported : 1) Reuse methods of waste thermosetting FRP by pulverizing into powders as fine aggregate and cement-replacing binder in repeated partly recycled (cascade recycled) concrete. 2) Dynamic tensile behavious of continuous carbon and glass fiber reinforced recyclable thermoplastic reinforcements applicable enough for lightweight precast concrete newly developed as ecomaterials gentle to the global environment. 3) Accelerated carbonation test of concrete by step response method as a new method of prediction of the service life of RC and FRPRC corresponding to the increase in the concentration of atmospheric CO_2 as one of the global environmental problems.
Keywords: Continuous fiber reinforced thermoplastic (FRTP), Continuous fiber reinforced concrete (FRPRC), Cascade Recycling, Ecomaterials design, Elemental Technology, Life cycle design, Long service life, Recyclability,

1. Introduction

Development of new building materials have been done so far from the viewpoint of pursuit of the frontier characteristics of lightweight, high strength and high durability in the case of such structural materials as steel, concrete and wood, and the amenity characteristics of high function and flexible design in the case of such non-structural materials as finishing polymer and glass. However, the characteristics of harmony with the global environment are becoming more and more required also for building materials and components as well as the characteristics of high performance and high function. In order to realize the sustainable construction, we have to consider the harmony among the environment, economy and safety. In this paper environment-conscious materials (ecomaterials) design aiming at the conversion of building structural composite materials, components and elements into eco-materials, eco-components, and eco-systems is discussed, paying attention to the establishment of fundamental technology as a basis for the sustainable construction. The concept of environment-conscious materials (ecomaterials) is newly proposed one to try to make an effective approach from materials side for the preservation of the global environment [1-2].

With the recent remarkable development of many types of advanced fibers with excellent material properties like: lightweight, high strength and elasticity, and high corrosion resistance such as carbon, aramid, glass fibers, there has been an increasing innovation in construction technology by effective application of fiber reinforced plastics and/or fiber reinforced cement and concrete as advanced composite materials. Many fruitful research results have been accumulated about fundamental and applicable properties of FRP reinforcements and concrete reinforced with these FRP reinforcements (FRPRC) [3-4]. In spite of many useful properties in service, however, many existing FRP reinforcements have been made of thermosetting resins such as epoxy and vinyl ester which are hard to be chemically resolved in time of demolition and recycling, and have too poor recyclability.

This paper deals with life cycle design of lightweight high strength precast concrete combined with continuous fiber reinforced plastic reinforcement as an example of ecomaterials design considering the compatibility of long service life with recyclability, because concrete and FRP are two main building structural composite materials most difficult to be recycled for the present [5].

2. Research Methods

Existing building structural composite materials and components such as steel reinforced concrete (RC) and FRP reinforced concrete (FRPRC) have many excellent characteristics. Extreme orientation for high performance such as high strength and high corrosion resistance, however, becomes obstacles when we recycle these structural composite materials and components in demolition after designed service life. We try to convert these structural composite materials and components into new recycling-oriented ones, taking into account the harmony of the long service life and recyclability. Figure 1 shows the comparison of concepts of new reinforced concrete with CFRP reinforcements with ordinary steel reinforced concrete, considering the compatibility of recyclability with long service life. As to steel reinforced concrete as one of the main building structural components in building field, for the present, we freshly remember a serious deterioration problem as “concrete crisis”. In order to solve this problem, new approach has been made of durability design for making longer the service life of steel reinforced concrete buildings, and further a new active movement has rapidly gained ground to use various types of new continuous fiber reinforced plastic (FRP) reinforcement replacing steel reinforcement liable to corrode. FRPRC using thermoset resins, however, are difficult to be recycled in demolition after designed service life. If we use FRP reinforcements made of chemically resolved resins, we can expect to convert FRPRC into ecomaterials gentle to the global environment. We aim to systematize such life cycle design and ecomaterials technology.

3. Research results

3.1 Ecomaterials Design of Concrete Composite Materials and Systems [5], [6]

Life cycle processes of ecomaterials design of building structural composite materials and components are shown in Figure 2. How to establish the harmony of long service life with recyclability is an important point of this ecomaterials design.

3.1 Three Research Results as Part of Elementary Technology

The following research results were obtained :

1) Reuse methods of waste thermosetting FRP by pulverizing into powders as fine aggregate and cement-replacing binder. [7],

Table 1 shows the experimental results of concrete mixed with pulverized FRP powder, and Table 2 shows the experimental results of fluidized concrete mixed with pulverized powder. It was found from these experimental results that concrete mixed with FRP powders show the material characteristics comparable to plain concrete.

2) Dynamic tensile behavious of continuous carbon and glass fiber reinforced recyclable thermoplastic reinforcements [8], [9].

Table 3 shows the materials properties and test methods of newly-developed recyclable continuous carbon and glass fiber reinforced thermoplastics (FRTP). Dynamic behavious of these FRTP was exmined by repeated tensile loding test. It was found that these newly developed FRTP are applicable for non-metallic reinforcements, having the characters of the harmony with the environment as well as satisfactory dynamic characteristics necessary for reinforcements for precast concrete.

3) Accelerated carbonation test of concrete by step response method as a new method of prediction of the service life of RC and FRPRC [10].

Accelerated carbonation test was done based upon the step response method by setting the environmental CO_2 concentration as shown in Figure 3 modeling the

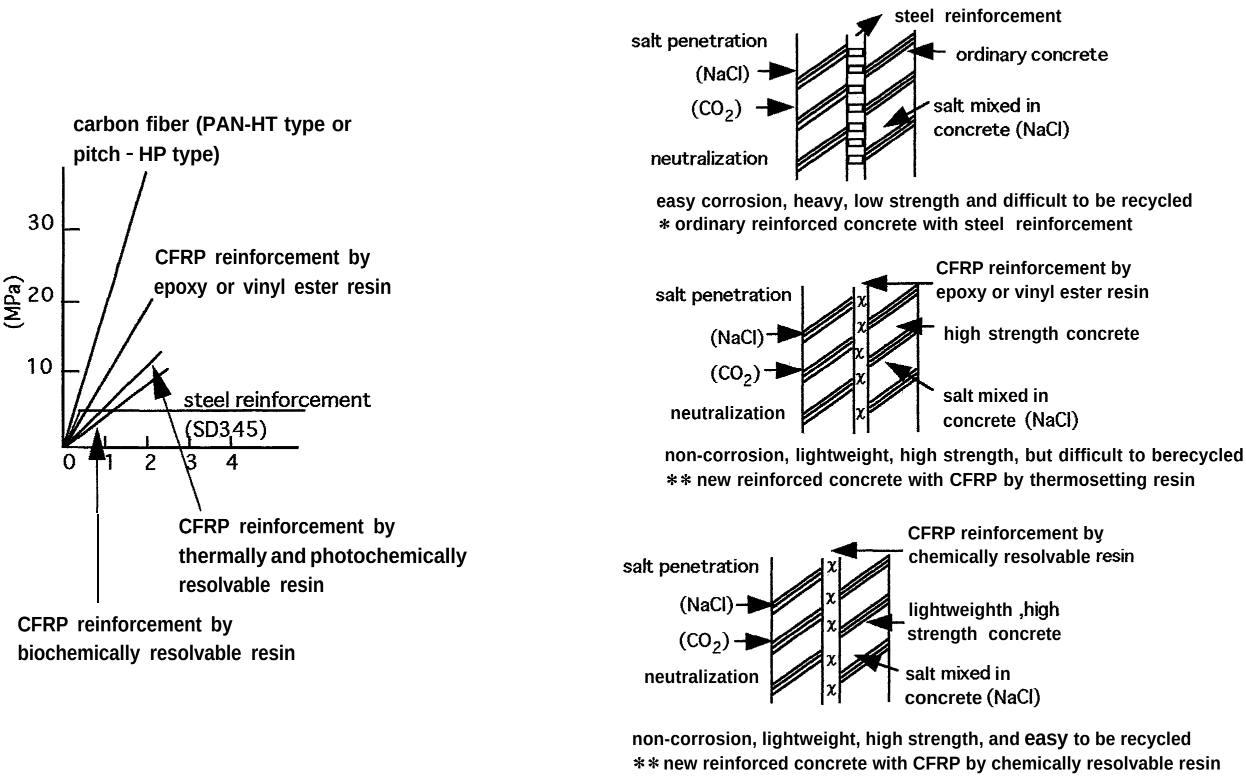


Figure 1 Comparison of Concepts of New Reinforced Concrete with CFRP Reinforcement with Ordinary Reinforced Concrete with Steel Reinforcement

Purpose	Production	Construction	In Service	Demolition / Recycle / Reuse
Environment-consicous materials design taking into account harmony of recyclability with high durability	Materials design considering in advance recyclability Building component FRP Chemically resolvable fiber + Chemically resolvable resin Precast lightweigt, high - strength concrete 1) Completely recyclable concrete by use of lime stone as coarse and fine aggregate considering in advance the regeneration of cement cf. Prof. Tomosawa of Tokyo University 2) Partly recyclable concrete by regeneration of lightweight coarse aggregate by crushing waste lightweight concrete cf. Prof. Kasai of Nihon University LCA(Life cycle assessment) at the time of production (CO_2 generat ion) (Energy consumption)	Design for easy demolition Hybrid Structure Column : Reinforced concrete with steel reinforcement Beam : New reinforced concrete with FRP reinforcement Bond : Steel fastner LCA at the time of construction * Materials design for selection and evaluation of FRPRC as building materials and components to be used for wanted building elements	Long service life design New methods of prediction of service life correspondent to the global environment problems Super high durability LCC in service LCA in service	FRP 1) Thermosets → FRP powder → Reuse as fine aggregate and cement - raplacing binder for mortar and lightweight concrete 2) Thermally resolvable resign 3) Photochemically resolvable resin 4) Biochemically resolvable resin ↓ Chemical processing Conversion into monomer and olygomer and wax → Resolution in soil Precast lightweight, high strength concrete ↓ Regeneratton of artificial lightweight coarse and fine aggregate → Reproduct ion LCA at the time of recycling (CO_2 generation) (Energy consumption) Evaluation of environmental load

LCD (Life Cycle design) PSL (Prediction of service life)
LCC (Life cycle cost analysis)
LCA (Life cycle assessment)

Figure 2 Processes of Environment-Conscious **Materials Design (Ecomaterials Design)** of **Precast Lightweight Concrete Reinforced with Continuous Fiber Reinforced Plastic**

Table 1 Experimental results of recycled concrete mixed with pulverized FRP powder (curing age 28 days)

FRP Ratio (%)	Slump (cm)	Water cement ratio (W/C) (%)	Sand aggregate ratio (S/A) (%)	Unit water weight (kg/m³)	Unit weight (g/2ℓ)				Air content (%)	Compressive strength (N/mm²)	Young' modulas (XI 0³n/mm²)
					Cement	sand	FRP	Glavel			
0	19.0	60	45.0	175	292	685	-	896	4.8	22.1	16.1
1	19.9	60	45.0	175	292	678	7	896	8.6	14.2	12.8
5	18.5	60	45.0	175	292	651	34	896	9.3	14.0	12.1

Table 2 Experimental results of fluidized concrete mixed with pulverized FRP powder (curing age 7days)

Types of FRP	FRP ratio (%)	Flow (mm)	W/P* (%)	Unit water weight (kg/m³)	Unit weight (g/2 ℓ)				High performance water-reducing reagent ratio (%)	Air content (%)	Compressive strength (N/mm²)
					Cement	sand	FRP	Glavel			
	0	495	35.0	51.8	486	860	-	806	2.0	3.6	64.7
Pluverized powder	5	405	35.0	51.8	462	860	24	806	2.0	2.9	63.0
Fly ash	5	418	35.0	51.8	462	860	24	806	2.0	3.9	63.2

*(cement + pulverized FRP powder or burnt FRP fly ash)

Table 3 Material Properties and Test Methods of Thermoplastic FRP's

Test items	Test method	Unit	PVC/GF	PC/GF	PVC/CF	PC/CF
Specific gravity	ASTMD792	—	1.50	1.34	1.51	1.35
Tensile strength	ASTM 0638	N/mm² (kgf/cm²)	129 (1320)	118 (1200)	347 (3540)	347 (3540)
Flexural strength	ASTM D790	N/mm² (kgf/cm²)	173 (1770)	169 (1720)	189 (1930)	312 (3180)
Flexural elasticity	ASTM D790	N/mm² (kgf/cm²)	7771 (79300)	6125 (62500)	21000 (212000)	21000 (212000)
Izod type impact strength	ASTM D256	J/m (kgf/cm²)	304 (31)	774 (79)	304 (31)	304 (31)

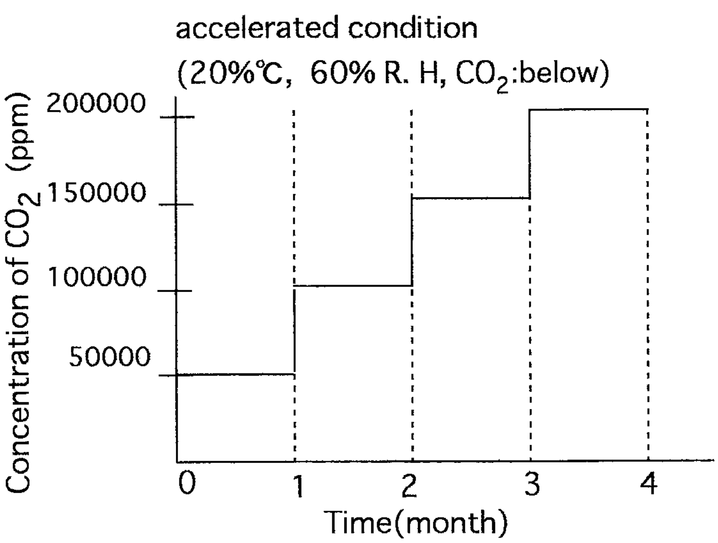
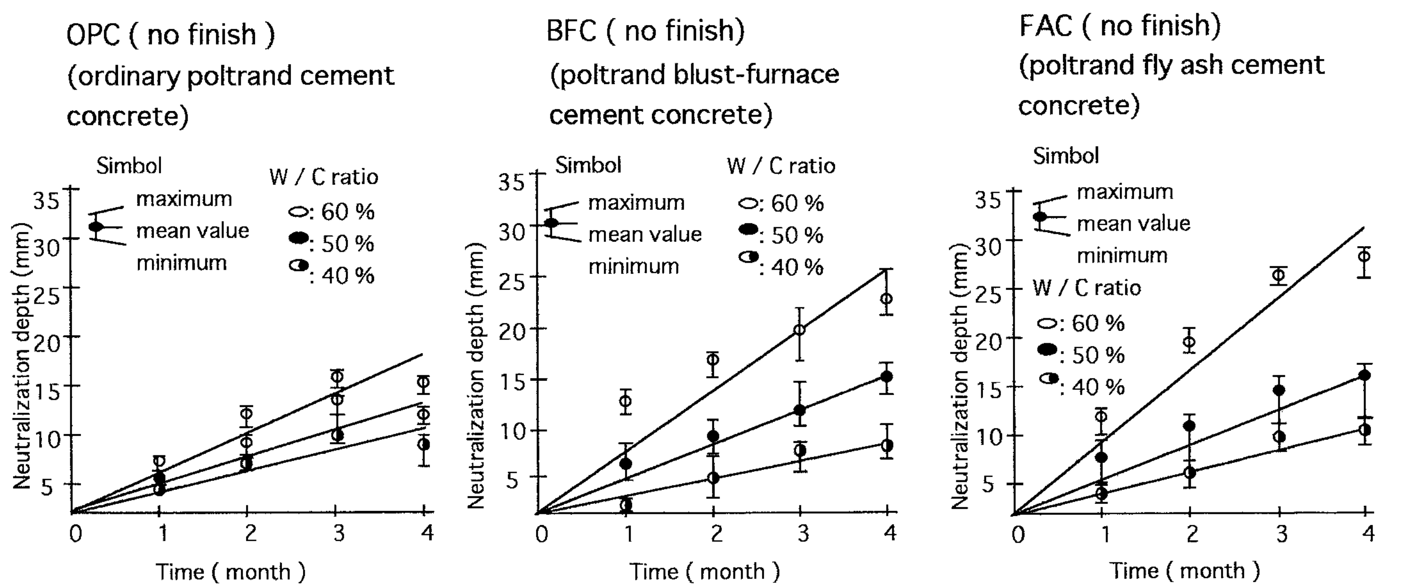
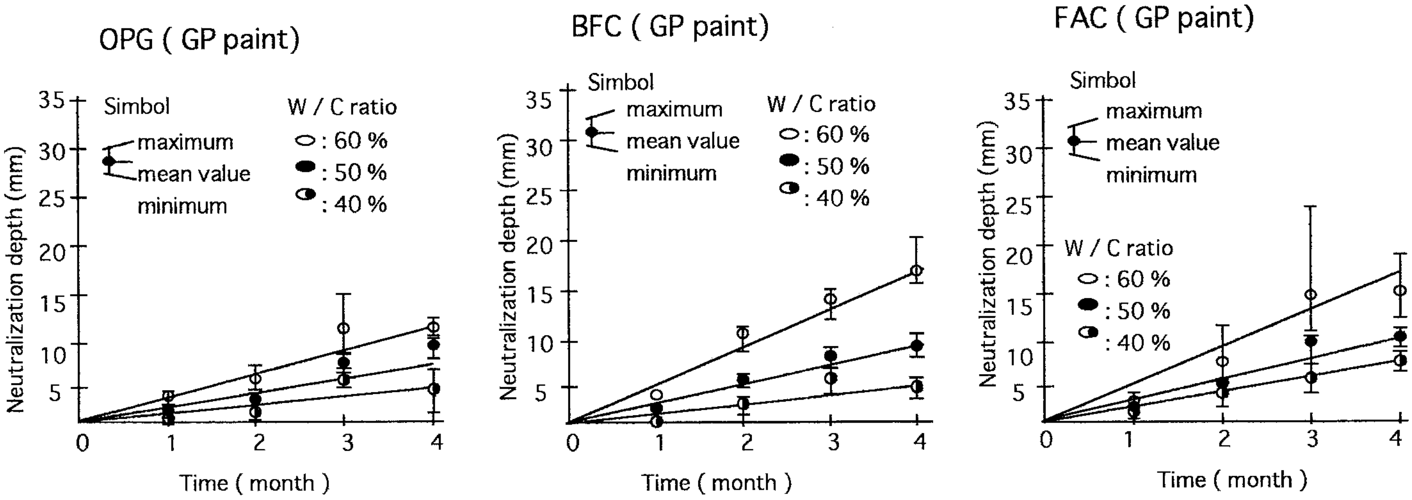


Figure 3 Accelerated Carbonation Test Method by Step Response



a) (Off - Form Concrete)



b) (Concrete Coated with Acrylic Type Paint)

Figure 4 Progress of Neutralizat of Various Types of Concrete by Step Response tendency of the increase in the concentration of the atmospheric CO2 for various types of concrete Linear law, not parabolic law was observed for the first time by this new accelerated carbon test method as shown in Figure 4 a), 4 b).

4. Conclusion

In order to convert building structural composite materials and component and/or elements into environment-conscious ones, ecomaterials design is proposed, paying special attention to the harmony of long service life with recyclability. Some elemental techniques to establish this ecomaterials design have been developed.

Lightweight high strength concrete components reinforced with recyclable continuous fiber reinforced plastic (FRP) rebars with thermally, photo-chemically and biochemically resolvable resins and fibers are recommended as ecomaterials design satisfying both the long service- life and recyclability of building materials and/or components.

Further, both repeated partial recycling (cascade recycling) of concrete, and reuse of thermosetting FRP rebars by pulverization as fine aggregate and cement-replacing binder in recycled concrete are considered.

In order to apply for recyclable non-metallic reinforcement for concrete structures, continuous carbon and glass fiber reinforced thermoplastics (CFRP and GFRP) have been newly developed. It was found that these recyclable FRP made of thermoplastics show completely elastic tensile behavious just as ordinary FRP (made of thermosets) reinforcement, and that in these thermoplastic FRP, stress concentration occurs dynamically in the fiber part as reinforcing materials for resins as well as in the environing parts of circular holes.

New predictive methods of the progress of carbonation of concrete and accelerated carbonation test methods have been established, considering the tendency of the increase in the concentration of atmospheric CO_2.

This ecomaterials design and elemental techniques will greatly contribute to establish the sustainable eco-construction, and eco-buildings, eco-cities and eco-societies in the future.

5. Acknowledgement

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6. References

1. Proceedings of RILEM Workshop on Building Materials and Environment, Nov. 18-19, at VTT (Center for Building Technology), Otaniemi, Finland, 1995
2. Report of Fundamental Research Based upon the Budget in 1992 Fiscal Year for Promotion and Adjustment of Science and Technology : Ecomaterials for the Preservation of the Global Environment (1993). Research Development Bereau of Science and Technology of Japan, Tokyo (in Japanese).
3. Syirayama, K., Kubota, T., Fukushima, T., Maruyama, T., Nishi, Y., Hitotsuya, Akihama, S., Fuminori, T., Tanaka, H., Nishida, K., Ito, H., Tanano, H., Nireki, T., Kasnino, N., Hisai, D. and Nakamura, S. "Study on Evaluation of Mechanical Characteristics of New Fiber Reinforced Concrete Composites (FRC) Mainly Using Carboa Fiber," Report of Building Research Institute, No.131, Tsukuba, 1991, pp.154. (in Japanese)
4. Shirayama, K., Maruyama, T., Nishi, Y. and Fukushima, T. Kashino, N., Yanagi, K., Nishida, K., Tanaka, H. and Ito, H. "CFRP Deformed Bar Reinforcement," Concrete 2000, E&FN SPON, London, 1993, pp.857-858
5. Fukushima, T., Yanagi, K. and Maeda, T. "Environmental Conscious Materials Design of Lightweight Precast Concrete Components with Recyclable FRP Rebars," Disposal and Recycling of Organic and Polymeric Construction Materials, E&FN SPON, London 1995, pp. 111-125
6. Fukushima, T., Kojima, A., Yanagi, K., Yoshizaki, Y. and Hayashi, T. "Ecomaterials Design of Building Structural Composite Materials and/or Components Considering Recyclability and Its Elemental Technology," Proceedings of International Ecomaterials Conference, Xi'an, China, Sep. 1 O-1 5, 1995, pp.263-266
7. Yanagi, K., Kojima, A. and Fukushima, T. "Physical Properties of Concrete Containing Scrapped FRP Fine Powder ," JCA Proceedings of Cement and Concrete, 1996, paper No. 161 (in Japanese)
8. Fukushima, T., Sakayama, K. and Hashimoto, S. "Dynamic Behavious of Continuous Carbon and Glass Fiber Reinforced Thermoplastics (CFRP and GFRP) for Recyclable Non-Metallic Reinforcement for Concrete Structures," Proceedings of the Third International Symposium on Non-mettallic (FRP) Reinforcement for Concrete Structures, Vol.2, Oct., 1997, pp.235-242
9. Fukushima, T., Sakayama, K. and Hashimoto S. "Application of Recyclable Thermoplastic FRP for Reinforcement for Lightweight Precast Concrete", Proceedings of the Fifth. Japan International SAMPE Symposium, Oct. 28-3 1, 1997, pp. 1457-1462
10. Fukushima, T., Yoshizaki, Y. and Hayashi, T. Accelerated Carbonation Test by Step Response Methods. Proceedings of the Seventh International Conference on Durability of Building Materials and Components, held on May 19-23, 1996, in Stockholm, Sweden : Durability of Building Materials and Components 7, Edited by C. Sjöström, E&FN SPON, London, Vo1.2. pp.1061-1070 (1996).

Moisture monitoring system based on a remote moisture sensor

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Abstract
The moisture monitoring system being developed provides a network of monitoring cells, centrally monitored, to give early warning of potentially damaging failures of building components, generating high and persistent moisture levels, which are known to cause decay and damage to timber and masonry. The most critical aspect of system design is the useful range of the sensors, and their performance and reliability are crucial to a low maintenance installation and long-term customer satisfaction.

The paper describes the development of a new moisture sensor to meet the requirements with respect to accuracy; no species calibration is needed. The sensor consists of two pairs of parallel electrodes, equivalent to a network of six resistances, providing the potential for measuring moisture gradients. Electrodes are embedded with a cylindrical, high durability wood buffer. Several existing measurement techniques are evaluated. Performance of a prototype used in connection with a datalogging system is described. Results demonstrate the possible benefit to the construction industry in all situations where there is the need for an accurate long term measurement of the moisture content (MC) of timber, for example, in purchase, treatment, construction and surveying.
Key words: Moisture sensors, timber, instrumentation

1 Introduction

Moisture is associated with a range of problems in timber. For example, warping, shrinkage and distortion in service can occur where substantial variations exist between the installation and final moisture content (MC) [1]. The resistance to decay is severely affected by the MC of timber as the colonisation of fungi is strongly dependent on the MC. For example, if the MC is above around 25% the probability of fungal decay increases dramatically, especially where the timber is classed as "non-durable" [2]. Hand-held moisture meters are frequently employed for monitoring MC, where individual readings are taken at selected points, these being limited to surface or near surface measurements. For resistance type instruments, if species and temperature corrections, grain orientation and possible moisture gradients are ignored the measured values could suffer large errors.

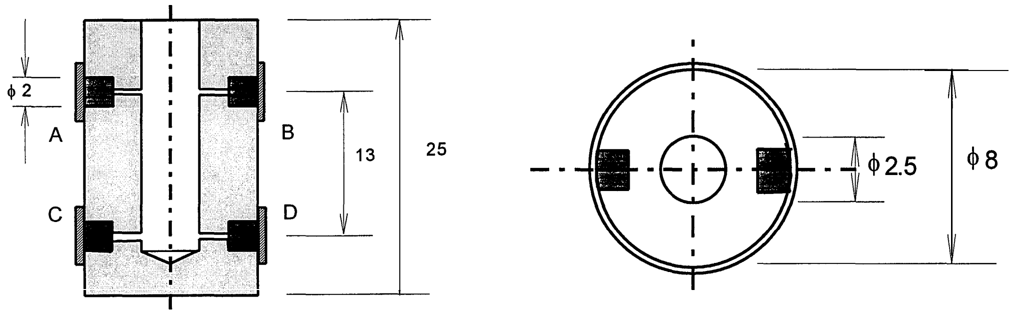
For large and/or inaccessible regions, moisture sensors with long term reliability, small enough to minimise disruption are needed for continuous monitoring. Extensive literature searches reveal that various types of sensor are in existence. [3] and [4] describe small wood sensors (approximate 4×4×15 mm). These are low-cost and easy to produce. In trials with similar sensors, the authors of this paper found that the main problem is in ensuring long-term reliable contact between the conductors and the wood surface. Inter-sensor variations have also been observed to be substantial. [5] describes a composite sensing probe able to measure resistance using stainless-steel rings at various depths in wood. However, the construction of these sensors appears to be involved and the probes are probably not inexpensive.

Sensors designed and produced by the authors' have the following characteristics: durable, low-cost, easy to produce and have small inter-sensor variability although individual sensors can be easily calibrated against oven-dried moisture contents. Small screw-type conductors ensure efficient long-term contact with the wood. Screw-type electrodes were employed very effectively in a previous project [1].

2 Moisture Monitoring System

2.1 Sensor Structure

Sensors employ wood buffers made from several species to ensure long term durability, 8 mm in diameter and 25 mm long. Two pairs of silver painted brass screw-type electrodes are inserted into the wood buffer 13 mm apart along the buffer grain (see Figure 1). A hole, 2.5 mm in diameter, allows the insertion of wires for connection to the electrodes. The 7-gauge shielded leads carry the signals over 4 m to the amplifiers. The isolating material (1 mm width) covers the electrodes to ensure that the electrodes do not touch the sample tested. The majority of the buffer is exposed inside the monitoring material in order that the buffer can reach equilibrium quickly. This sensor is referred to as GD1 hereinafter. In use, although the buffer maybe contact the test sample, this does not noticeably affect the final readings because the resistance of timber strongly depends on the contact of electrodes and buffer. For equilibrium moisture condition, the resistance of the buffer (R_b in Figure 2) is very much less than that of the sample tested (i.e. R_s in Figure 2), that is, $R_b << R_s$, therefore, overall the resistance $R = R_b // R_s \cong R_b$.



(a) Side Section (b) Top view

Figure 1 Sensor model; dimension in mm

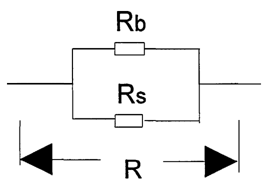


Figure 2 Resistance relation between buffer and sample tested

A range of wood species for the buffer have been carefully selected based on the application purpose. Buffer species are selected based on the permeability, durability and resistivity. Generally, the priority factors chosen are high permeability and low resistivity of buffer species. But for long-term monitoring of MC, durability is high priority.

2.2 General description of the circuit

The block diagram of the circuit is shown schematically in Figure 3. Unlike the commonly used full and half bridge methods, this approach requires no intermediary (and well-characterised) high-resistance standards to bootstrap up the resistance scale. Because the moisture meter should be able to operate over a wide range of moisture contents, a logic seeking strategy to find the appropriate range has been used. In

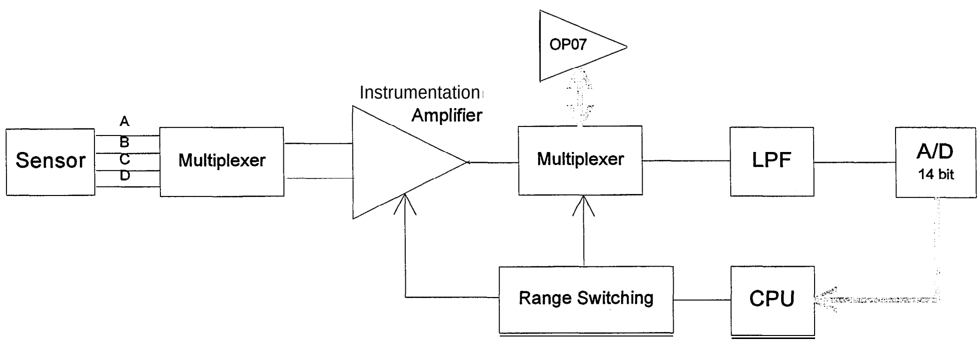


Figure 3 Schematic diagram of the moisture meter. (A/D: analog to digital converter; CPU: central processing unit; LPF: low pass filter)

Figure 3, the instrumentation amplifier has variable gain from 1 to 1 0^4. A high accuracy operational amplifier (OP07) is reserved as second-stage amplifier. These realise a practical operating range between 1kΩ and 100GΩ. Under simulated conditions, the meter measures accurately from 8 to 75 percent moisture content; in practice, however, the readings above the wood fibre saturation point should be considered only as "useful" as a resistance varies slowly with MC in this region.

2.3 Detailed considerations for improved performance

1. Species compensation

Since the wood species for the buffer in GD1 is fixed, relating resistance to wood MC can be determined in the laboratory based on oven-dried measurements of virtually identical samples. For this reason, no species correction are needed for measurements in varying samples. The final MC readings for samples tested can be determined from the relationship established in [6]. This database will be included in the microprocessor firmware, and the reading can be transformed automatically.

2. Polarisation consideration

This system solves the problem of polarisation by using an alternating polarity test sequence. Each sequence consists of the application of a positive polarity voltage, and after an appropriate delay, measures the current; the voltage polarity is then reversed and the current measurement again after the same delay time. This is repeated for a number of cycles (usually about seven) until the user observes stable readings. The instrument then calculates the resistance based on a weighted average of the last four readings.

3. Accuracy improvement

Current moisture meters only measure MC at the point of test. The test data in next section reflects that in some circumstances there are different MC readings from two pairs of electrodes in different depth of test sample. To understand the resistance variation in different directions within the buffer, it is essential to appreciate the electrical equivalent circuit of the measurement process; this is shown in Figure 4. Refer to Figure 1 for the equivalent points on the sensor. Because both R_3 and R_4 are resistances along the buffer grain, and R_5 and R_6 are resistances between two pairs of diagonal electrodes, the following assumptions can be made: $R_3 = R_4 = R_a$; $R_5 = R_6 = R_d$. Figure 4(a) can then be further simplified, Figure 4(b). If all of resistances can be measured, the final values calculated from these resistances will be more accurate measure of MC than that from a single resistance.

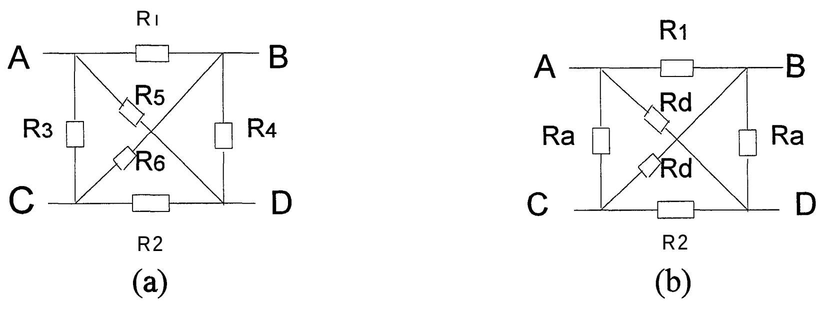


Figure 4 (a) Equivalent circuit diagram of GD1 sensor
(b) Simplified resistance network

4. Noise reduction

Numerous sources of error relating specifically to high resistance measurements (equivalent to low moisture content) have been analysed in [7]. Results of these analyses are still germane to our present work. The two leading limiting factors for obtaining a high accuracy are leakage currents and noise. In order to limit these factors, extensive attention should be paid to correct shielding and guarding, especially of the input terminals, i.e., from electrodes to circuit. Currently, screened cable has been used to transmit the signal. Input cables are shielded throughout. PTFE substrates substitute ordinary PVC for the circuit boards, effectively reducing the leakage current through the printed tracks. Guard pins adjacent to both input connections of the instrumentation amplifier have been used to drive circuit board and input cable guards to maintain extremely low input bias current.

3 Calibration and results

At present, most moisture meters use empirical equations, for example,

$$\log[\log(R)-4]=1.009-0.0322M$$

to relate resistance, R in Ω, along the sample grain to the percentage moisture content M, at temperature 20°C [8].

Figure 5 shows the variation in the electric resistance with moisture content. The shaded area shows the region in which 90% of commercially available species fall [8]. Carl1 [3] and Skaar [8] have well explained the electrical properties of wood, and here we mainly concentrate on the behaviour of the GD1 sensor.

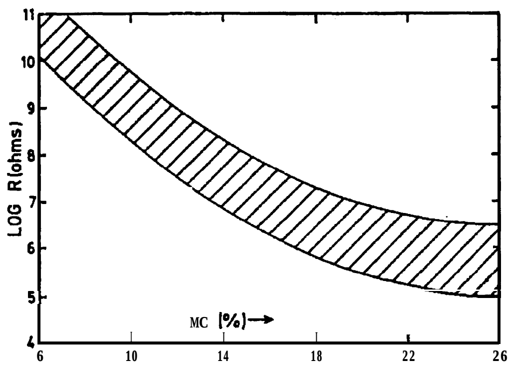


Figure 5 Electric resistance versus MC for most of commercially available wood species [8]

3.1 Comparison of three types of sensor readings

A limited calibration was carried out using timber species, Opepe and Beech, for GD1 sensor buffer. These choices of timber were dictated by the groups own particular requirements. Recalibration is necessary if other timbers are used.

Holes, 10 mm in diameter, were drilled into a number of Beech samples. The GD1s were pushed into the holes and the holes were sealed with silicon caulk to ensure that the outside atmosphere does not affect the buffer environment. Sensors were not inserted near obvious defects to ensure that the electrodes give more consistent readings. Three sensors were installed in the same conditioning chamber at 75% relative humidity (RH) and 20°C. Table 1 shows some of the MC measurements. Measurements were taken over a six month period. Although there is some variability between sensors, the fluctuation for a given sensor were less than 0.5% MC, showing long term reliability.

Table 1 Percentage MC readings from three different types of electrodes

(CT type sensor is type referred to in [3])

	Electrodes	MC
Set 1	Pin-type	14.1
	CT type sensor	11.7
	GD1 top pair	12.9
	GD1 bottom pair	12.9
Set 2	Pin-type	14.4
	CT type sensor	13.1
	GD1 top pair	12.9
	GD1 bottom pair	13.1
Set 3	Pin-type	13.7
	CT type sensor	12.8
	GD1 top pair	13.7
	GD1 bottom pair	14.1

In Table 1, the GD1 buffers of set 1 and 2 are Beech and that of set 3 is Ramin. Although the samples have not been oven-dried and we do not know the exactly final MC, it is very interesting that the readings from GD1 sensors are systematically lower compared with those from direct pin insertion. The CT type sensors consistently lower readings than the GD sensors, presumably being caused by very high contact resistance.

Pin-type electrodes and wood sensor can only reflect the MC at the depth of contacting with the samples. There is commonly moisture gradient inside the sample at any time, the average value from GD1 sensor gives more reasonable results.

The speed of moisture sorption greatly depends on the surface to volume ratio of the sensor. For the CT type wood sensors, only top end exposed to its environment, so response of wood sensor is relatively slow especially under drying conditions compared with GD1 sensor.

3.2 GD1 in specified RH

Table 2 gives a measure of MC in various RH conditions for an individually calibrated sensor. Only if an individual calibration data is available for each sensor can an “absolute” MC be resolved to the precision given in this table. However, even without an individual calibration data, the table gives the tracking sensitivity of a sensor.

Table 3 shows the MC readings based on the individual resistances of electric network in Figure 4(b). At present, the relationship between the overall MC and the resistances both along the wood grain and perpendicular to the grain are being work

Table 2 Sensor calibration, showing mean values of MC

MC % / Sensors	Percentage RH at 20°C			
	33	66	76	93
Oven-dried MC	8.48	13.50	15.12	22.5
GD1 No.1	7.78	12.34	14.60	15.84
GD1 No.2	8.00	13.52	14.94	17.42
GD1 No.3	--	11.92	14.22	15.62

out. The data in Table 3 indicate uncertainties in the MC for a given RH or calibration measurement. On average, the uncertainty between measurement from the two sensors is less than 0.3%. An investigation is on the way to estimate in the uncertainty of the "absolute" MC if individual sensor calibrations are not available. It is quite difficult to offer a universal calibration for the sensors as this will be buffer material-specific and will have fabricating uncertainty; however, other workers should have no difficulty in using the technique presented here and calibrating for their own particular needs.

Table 3 MC readings based on individual resistances defined in Figure 4(b)

Conditions	Percentage MC readings from			
	R1	Ra	Rd	R2
GD1 No.4 at RH 55%	11.7	11.7	11.1	11.4
GD1 No.5 at RH 55%	11.4	11.5	11.3	11.5
GD1 No.4 at RH 75%	15.7	15.6	15.8	13.8
GD1 No.5 at RH 75%	14.9	15.1	14.8	15.1

4 Discussion and Conclusion

The data obtained to date shows good consistency and reproducibility. However, various improvements are necessary, partly for automation of the set-up and partly to ensure high accuracy.

Early prototype sensors indicated much variability. General improvements have been made to sensors by improving machining techniques using uniform batches of materials, dimensional uncertainties and consistent sized screws. Screw electrodes are secured into precision holes for minimising contact resistance variations.

Very roughly, for every 10°C deviation of temperature from the calibration temperature of 20°C, an error of 0.5 % MC results, although the current tests have been performed at constant temperature, 20°C. Calibration over a range of suitable temperature (e.g. 0°C to 30°C) is necessary for in-situ use. Suitable thermocouple sensors will be introduced into the buffers to automate temperature compensation.

Equilibrium MC values are history dependent, i.e., the final MC depends on whether the buffer is absorbing or losing moisture. This hysteresis effect can be substantial under certain conditions, affecting the readings by typically up to 1% MC. Investigations are underway to determine procedures for compensating for this effect.

In conclusion, the sensors described provide stable readings, and the data collected indicated the reliability in the long term. By using measurements from effectively a network of resistors, results are more accurate and more reproducible.

The manufacture of electrodes is straight-forward and based on low-cost materials. Inter-sensor variation in performance is being minimised by improved machining and engineering, although there will always be slight variations between sensors caused by material variability. The sensors have the potential for detecting moisture gradients even though this facility has yet to be exploited.

5 References

1. Ahmet, K. et al (1995) The moisture content of internal timber, Building Engineer, Vol.70, No.2, pp18-20
2. TRADA Technology Ltd. (1991) Moisture in timber, TRADA Wood Information, section 4, sheet 14
3. Carll, C. and Tenwolde, A. (1996) Accuracy of Wood Resistance Sensors for Measurement of Humidity. Journal of Testing and Evaluation, Vol. 24, No. 3, pp154-160
4. Tenwolde, A. and Courville, G.E. (1988) Instrumentation for monitoring moisture in building envelopes, ASHRAE, HI-85-22, No.3, pp1105-1115
5. Forrer, J.B. and Vermaas, H.F. (1987) Development of an Improved Moisture Meter for Wood. Forest Products Journal, Vo1.37, No.2, pp67-71
6. Ahmet, K. Dai, G. et al Experimental procedures for determining the equilibrium moisture content of twenty timber species. (Submitted to Forest Products Journal)
7. Chen,G.C.C. et al (1995) Accurate Self-Checking Digital Teraohmmeter. IEEE Transactions on Instrumentation and Measurement, Vo1.44, No.2, pp 192- 195
8. Skaar, C. (1988) Wood Water Relations, Spring-Verlag, New York

Environmentally-Sound Building Technologies

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Abstract
Referring to numbers of international scientific reports it arises that Sustainable Building Constructions are the only acceptable possibilities yet.
The Sustainability of a construction deals with responsible choices of materials and energies as well as similar choices of production and execution.
The so-called Porcupine Diagram shows the whole lifecycle or flow of building materials and illustrates the environmental impact dramatically.
As a conclusion from various research studies, concerning sustainable building, it became clear that the principles of "Thinking globally - acting locally", "Short as well as Long term planning", "Attunement to all Kinds of Recyclingprocesses", "Conservation of Resources" but also "Internalisation of the Problems" has to be considered honestly in order to be able to build sustainable. Human(e) Ecology, Bionics, Harmonics and new paradigmas, including ethical dimensions will help to find (re)new(ed) approaches and technologies towards sustainable building.
The author developed the necessary modells, methods and design aids, often translated into rules of thumb in order to support sustainable building in an efficient and even relatively easy way.
The choice of materials and technologies has to answer already fundamentally the demands for a healthy Indoor Environment. For the realisation of a qualified build environment the Right for the Environment is essential, which has to be supported by Legal and Procurement Practices. An environmentally-conscious Management will be needed to get the things done.
Together with such an integral view - the development and application of an environmentally-sound building technology might be one of the central tasks in order to reach results, which checked by Environmental impact and assessment methods, can be accepted. Proper Design aids and already rules of thumb lead to rather succesful results.

Keywords: Life Cycle - use and reuse - recycling

Eiwironmentally-Sound Building Technologies

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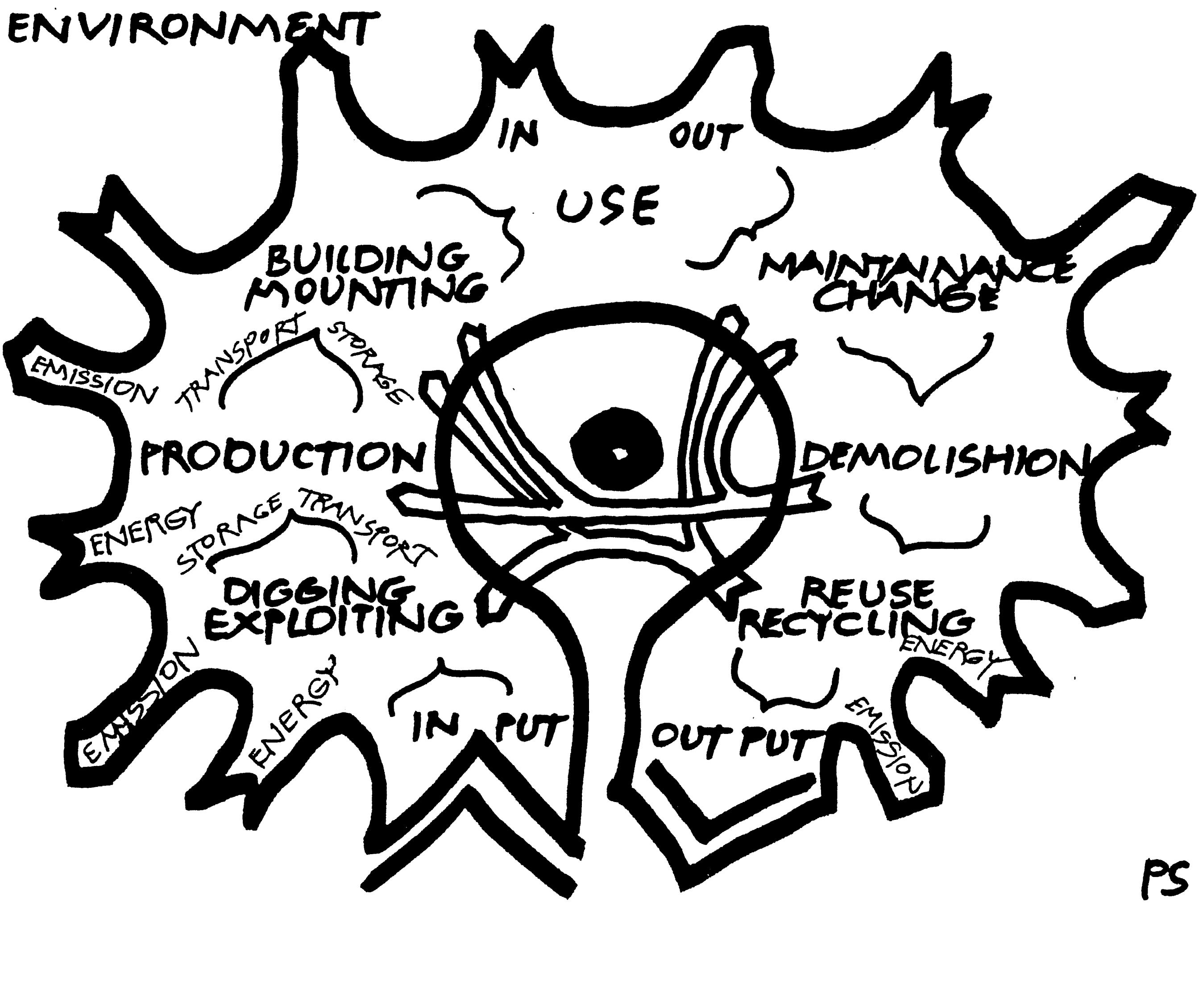

Figure 1
The Porcupine Diagram shows the whole life-cycle or flow of building materials and illustrates dramatically the environmental impact.

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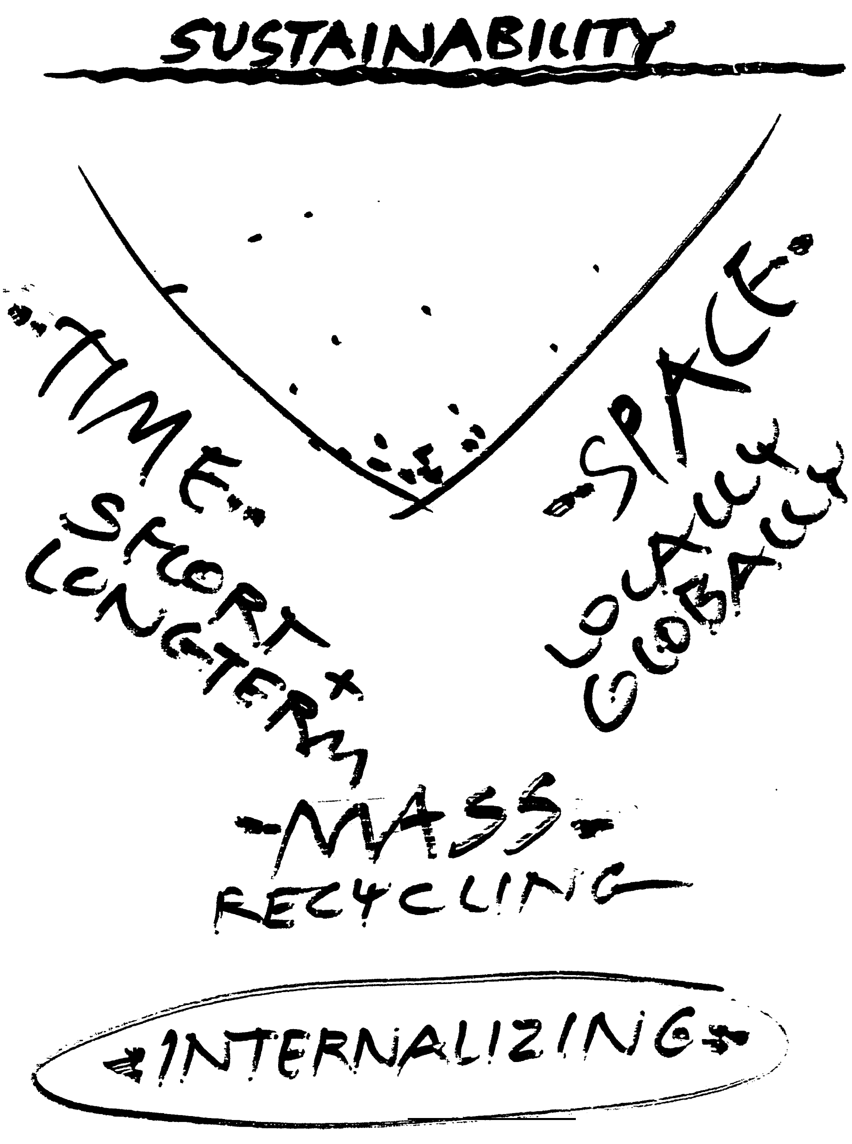
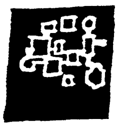


Figure 2
The Principles which have to be respected in space and time together with the most important namely the Internalisation of the actual problem.

The author developed the necessary modells, methods and design aids, often translated into rules of thumb in order to support sustainable building in an efficient and even relatively easy way.

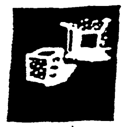
The choice of materials and technologies has to answer already fundamentally the demands for a healthy Indoor Environment. For the realisation of a qualified built environment the Right for the Environment is essential, which has to be supported by Legal and Procurement Practices. An environmentally-conscious Management will be needed to get the things done.

1. Location, Orientation, Use



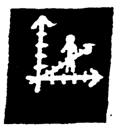
Choose a healthy site, consider the orientation, optimize the function for a practical use.

2. Space and Mass



Shape useful (closed or open) protecting space. Include identity and expression into the building mass.

3. Canon, Modular Coordination

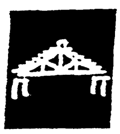


Apply harmonious and ergonomical measures, in numbers. dimensions. weights - modular coordinated - eventually in a meaningful way.

4. Indoor Climate, Installation, Furnishing

Create a cosy and comfortable indoor climate with minimal installations and a flexible equipment and furnishing in order to earn a suitable atmosphere.

5. Structure and Construction



Design (load carrying) sheltering structures simple and understandable. durable constructions. which do not demand various kinds of means (e.g. eievators) because of their gigantic character.

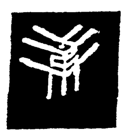
6. Energy and Material

Use mainly durable. sustainable. endless (available/growing). easy reusable or recycleable. soft. clean. "natura", energies and materials.

7. Production & Building Proces

Produce in a humanly, healthy way with a wise choice concerning handicraft or industry, selfheip or automatization and in cooperation and participation on ail possible levels.

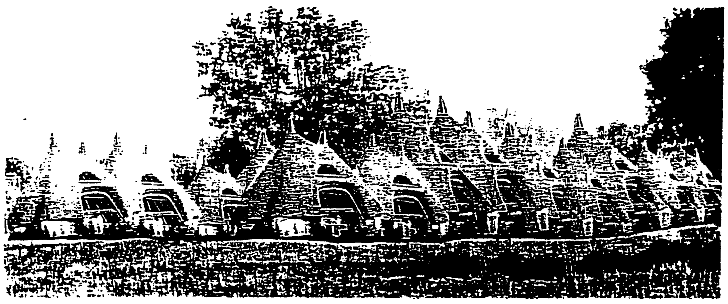
8. The Art of Joining

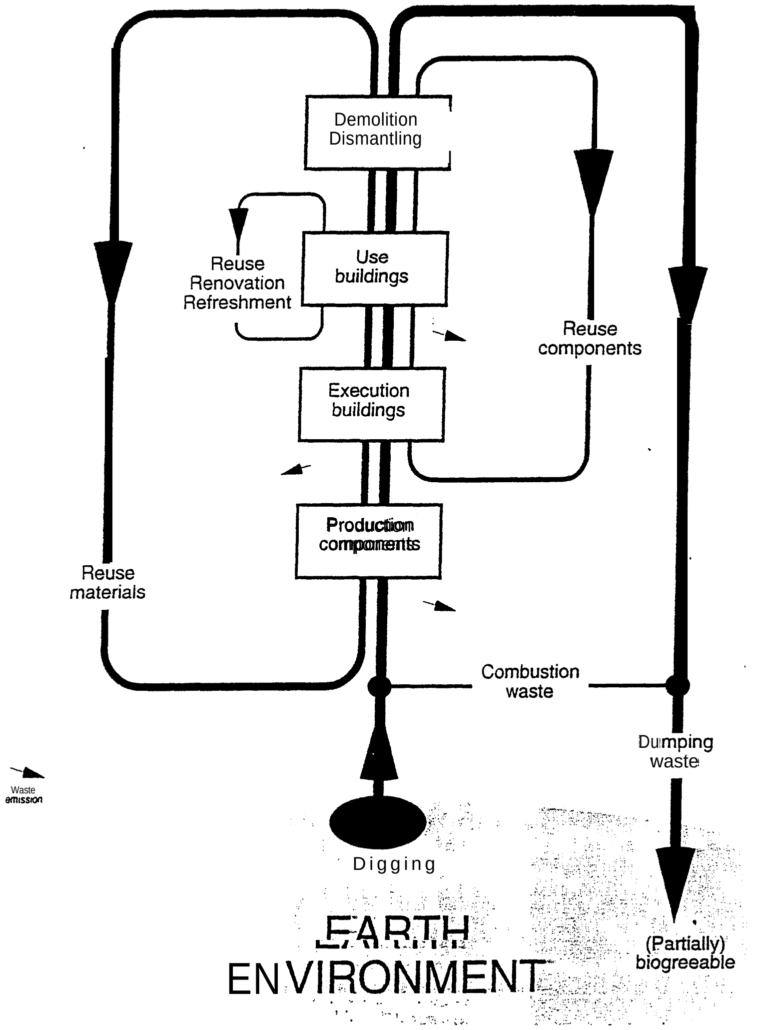


Joint/connect/compose all building parts or elements in a harmonious way. rather solid. but demountable. simply efficient. Joints as nuclei determine (already) the whole.

Figure 3
Some vital rules of thumb structured along the 8 Components in order to reach a suitable built and Sustainable Environment.

Together with such an integral view - the development and application of an environmentally-sound building technology might be one of the central tasks in order to reach results, which checked by Environmental impact and assessment methods, can be accepted. Proper Design aids and already rules of thumb lead to rather succesful results.





Figuur 1 Stroomschema van bouwmaterialen (Van Gassel en Schmid)

Figure 4
An example of a neighbourhood of "another" future fully based on a health and environment scenario carried amongst others by the insight into the lifecycles of building materials.

References

- Schmid, P. *(1986) Bio-Logische Baukonstruktion, Wege zu einer integralen Bau- und Ausbautechnik,* Mensch- und Umweltorientierte Hochbaukunde, Atlas einer human-bkologischen Baukonstruktionslehre, Verlagsges. R. Müller, Köln.
- Schmid, P. *(1986) The Instrument of an Integral bio-logical Architecture, designaids for housing and built environment,* 1 lth World Congress of Sociology, New Delhi, India.
- Schmid, P. *(1986) Holistic and Bio-Logical Light Weight Structures for Healthy and Individual Housing* 1 st international conference on lightweight structures in architecture, Sidney.
- Schmid, P. *(1986) New Building Concepts on Totality-Proces-Detail - Ecological Architecture (SHE),* Congres of the Society for Human Ecology 'Human Ecology: Research and Applications', Bar Harbor, Maine, U.S.A.
- Schrnid, P. (1987) *Integral Bio-logical Architecture,* 13. Kongress der Intemationalen Gesellschaft zur Erforschung von Zivilisationskrankheiten und Umwelt (SIRMCE), Lausanne.
- Schmid, P. (1987) *The Gaia Building System,* International Conference on the Design and Construction of Non-Conventional Structures '87, London.
- Schmid, P. (1988) *Architecture-Ecology-Health,* 3rd International Conference of the Society for Human Ecology - SHE - San Francisco, U.S.A.
- Schmid, P. (1989) *Building on Peace,* Key-note paper, International Prague Assembly of architects, planners and designers for professional actions against ecological disaster, homelessness and armament race, Palace of Culture Prague, CSFR.
- TUE, IFAM (1990) *Minimalisering van de Milieubelasting in de Woningbouw,* onderzoekrapport, i.o.v. S tichting Milieubewustzijn, Hilversum, Amsterdam - Eindhoven.
- Schmid, P., Haas, M. *(1990) Bio-logisch bouwen en wonen, gezond voor mens en milieu,* A&h-Hermes, Deventer.
- Schmid, P. (1991) *House of Another Future,* 9th International Svedala Symposium on Ecological Design, Svedala, Sweden.
- Schmid, P. (1992) *Integrated Development (Gaia Building Systems),* European Cities: Growth and Decline, International Conference in The Netherlands, Den Haag.
- Schmid, P. (1994) *Sustainability and Building,* CIB Conference, U.S.A.
- Schmid, P. (1995) *The World a Green School for Everybody,* Environmental education for the whole society, A contribution towards sustainable environment,, International Conference Environmental Issues Education and Training, University of Mateja Bela, Banska Bysttica, Slovak Republic.
- Schmid, P. (1995) *Sustainable Architecture,* International Symposium 'A Vision of architecture of the 2000's: Green and glocal architecture' on behalf of the 50th anniversary of the AIK-Architectural Institute of Korea, Seoul, Korea.
- Schmid, P. *(1996) The Different Houses of the Nations on one World, The common Sustainable Habitat reflected in the Joint,* XXIVth IAHS World Housing Congress, Ankara, Turkey.
- Schmid, P., P'al, G., Liddell, H., Halliday, S. (1997) *Green Arrows from Gaia International,* Sustainable Architecture in Auckland and Wellington, New-Zealand.
- Schmid, P., Liddell, H. (in preparation) *An Introduction to Ecological Design.*

Towards a new integrated IS0 - standard for sustainable building

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Abstract
The International Organization for Standardization, ISO, is currently producing standards for sustainable development within the industry, in its effort to minimize negative influence on the environment and to promote a long-term resource economy. This paper gives a state of the art review of the current work within IS0 14000 series (environmental management), IS0 9000 series (quality management) and outlines the second draft for an ISO-standard for Service Life Planning of Buildings (ISO/ TC59/ SC 14). This paper also highlights the need to integrate considerations concerning sustainability in building in the current work within ISO/ TC 59/ 14. This can be developed from a basis of scientific knowledge and empirical experience and by utilizing the principles of IS0 9000 and IS0 14000 series.
Keywords: Durability, service life, standards, sustainable building.

1 Introduction

Organizations of all kinds are increasingly concerned to achieve and demonstrate sound environmental performance by controlling the impact of their activities, products or services on the environment, taking into account their environmental policy and objectives. They do so in the context of increasingly stringent legislation, the development of economic policies and other measures to foster environmental protection, and a general growth of concern from interest parties about environmental matters including sustainable development.

International standards covering environmental management are intended to provide organizations with the elements of an effective environmental management system which can be integrated with other management systems. All these international standards are not intended to be used to create non-tariff trade barriers or to increase an organization's legal obligations.

The main ISO-standards for environmental management is the IS0 14000-series. This standard shares all management system principles with the IS0 9000-series of quality systems standards. Thus, IS0 9000-series can be used as basis for all environmental management systems.

The work within ISO/ TC59/ SC14 as described below, aims to give guidelines for sustainable building by utilizing the principles of IS0 9000 and IS0 14000 in a model for service life planning of buildings.

Unfortunately, all the ISO-standards in this area, except the standard ISO/ TC59/ SC14, are addressed to a general use and not for people concerned with building. In every day life, when problems must be solved "now", these standards are not easy to use for the common man who needs standardized knowledge in the field. For this reason, it is important to initiate a new work item for developing an ISO-standard, which includes principles from all the existing standards for sustainable building as described in the next chapters.

2 Aims

The purpose of the work presented here is to:

- To give a state of the art review on existing international standards for sustainable housing
- To outline the current work within IS0 for the development of standards for design life of buildings
- To propose guidelines for linking IS0 9000 and IS0 14000-series to the current work within ISO/ TC59/ SC14 "Design Life of Buildings".

3 State of the art review

3.1 IS0 9000-series

The IS0 9000 series contains International Standards dealing with quality systems and quality management that can be used to external quality assurance purposes. The alternative quality assurance models in those standard series, contains distinct forms of "Functional or organizational capability" suitable for two-party contractual purposes.

The five standards of the IS0 9001-series as mentioned below, give the basic guidelines for quality assurance and are now broadly used in all building processes:

- IS0 9000, Quality management and quality assurance standards - Guidelines for selection and use. This standard is to be used to clarify the distinctions and relationships among the existing quality concepts. It can be also used for the selection and use of the standards for quality systems and quality management (IS0 9001-9004).
- IS0 9002, Quality systems - Model for quality assurance in design/ development, production, installation and servicing. This standard is to be used when conformance to specified requirements is to be assured by the supplier during several stages which may include design/ development, production, installation and servicing.
- IS0 9002, Quality systems - Model for quality assurance in production and installation. This standard is to be used when conformance to specified requirements is to be assured by the supplier during production and installation
- IS0 9003, Quality systems - Model for quality assurance in final inspection and test. This standard is to be used when conformance to specified requirements is to be assured by the supplier solely at the final test.
- IS0 9004, Quality management and quality system elements - Guidelines. This standard is to be used to describe basic elements for carried out and implementing a quality system.

3.2 IS0 14000-series

The IS0 14000-series are currently in a development process. The following ISO-documents are now implemented as international standards:

- IS0 14001, Environmental management systems (EMS) - Specification with guidance for use. This standard can be used to specify requirements for an environmental management system, to enable an organization to formulate a policy and objectives taking into account legislative requirements and information about significant environmental impacts. It applies to those environmental aspects, which the organization can control and over which it can be expected to have an influence. It doesn't itself state specific environmental performance criteria.
- IS0 14004, Environmental management systems (EMS) - General guidelines on principles, systems and supporting techniques. This standard can be used to provide guidance on the development and implementation of environmental management systems and principles, and their co-ordination with other management systems. The guidelines in the standard are applicable to any organization, regardless of size, type, or level of maturity, that is interested in developing, implementing and/or improving an environmental management system.
- IS0 14 10, Guidelines for environmental auditing - General principles. This standard can be used to provide general principles of environmental auditing that are applicable to all types of environmental audits. Any activity defined as an environmental audit in accordance with this standard should satisfy the recommendations given in it.

- IS0 1411, Guidelines for environmental auditing - Audit procedures - Auditing of environmental management systems. This standard can be used to establish audit procedures that provide for the planning and conduct of an audit of an EMS to determine conformance with EMS audit criteria.
- IS0 1412, Guidelines for environmental auditing - Qualification criteria for environmental auditors. This standard can be used to provide guidance on qualification criteria for environmental auditors. It is applicable to both internal and external auditors. Criteria for the selection and composition of audit teams are not included, reference is made to IS0 14011 for information in this subjects.

The following ISO-documents are now in a development stage and will be implemented as international standards during 1997-98:

- IS0 1420-series, Environmental declarations and marking
- IS0 143 1, Environmental performance
- IS0 14040-series, Life cycle analysis (LCA)
- IS0 14050, Environmental terminology.

3.3 ISO/TC 59/SC 14 - Service life planning of buildings

This IS0 draft of an international standard for service life planning of building is currently developed within ISO/TC 59/SC 14 (former committee notation: ISO/TC 59/SC 3/ WG 9). This document [1] presents the generic principles, which can be applied in estimating the expected life of a building of any type to be built in any environment. It can also be applied in estimating the remaining life of an existing building. The Standard is in five parts as follows:

- Part I: general principles for evaluating whether the expected service life will be at least as long as the design life
- Part II: methods to be used in determining the expected life
- Part III: information on quality assurance, maintenance and performance auditing.
- Part IV: references to relevant standards, other literature and a glossary
- Part V: recommends formats for the data to be used and the reports to be generated.

The standard is planned to serve designers, owners, potential buyers/ investors, educators, etc. and the benefit they should gain from it. It will point out that while it is difficult (sometimes impossible) to make precise estimates of building life, the availability of a standard approach will put estimates on a common basis. The methodology used for prediction of service life of the building component follows the principles of the British, Japanese and Canadian national guides for service life planning of building [2].

4 Summary and conclusions

From what has been described above, the following conclusions can be made:

- Environmental optimization of every product, project, and enterprise in the building industry and real estate management becomes more and more as natural and as indispensable as an optimization from the viewpoint of business economics. In this paper, the challenge of the development of a new international standard for sustainable building has been described on the basis of existing ISO-standards and IS0 work items. The need of many interrelated standards forming a logically-consistent, coherent framework for sustainable building is pointed out.

- As described previously, international standardization for sustainable building is fragmented in a number of standards which are information intensive. At present, it is difficult, if not impossible, to glean the needed standard information from the scattered sources in the above mentioned standards. As such, a new work item has to be initiated to integrate all standardized knowledge which deals with the building and its environmental impact from a life cycle perspective with the current work within ISO/ TC 59/ SC 14 " Design Life of Buildings".
- While, sustainable building requires a large measure of knowledge the utilization of computer-based standardization will become necessary. Routines to facilitate the use of computer in all standardization are in place [3].

5 Acknowledgements

The authors wish to acknowledge that, development of these ideas concerning standardization of sustainable building owes much to discussions with others, particularly with members of the technical committees in CEN, ISO, CIB and RILEM.

6 References

1. Browne, D. R., Soronis G. (1996). Standard for Service Life of Buildings: Part-1 General Principles. *Proceedings of the Seventh International Conference on Building Materials and Components, 7BMC*, Stockholm, Sweden, May 1996.
2. Soronis, G. (1992). Standardization for Design Life of Buildings: Utilization in the Design Process. Construction and Building Materials, Vol. 10, No. 7, 1992.
3. Frohnsdorff, G. J. Martin W. J. (1996). Towards Prediction of Building Service Life: The Standards Imperative. *Proceedings of the Seventh International Conference on Building Materials and Components, 7DBMC*, Stockholm, Sweden, May 1996.

The effects of mineral fines on thermal properties of wood composites

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Abstract:
Large quantities of waste generated from aggregate quarries or from the production of stone building materials are present in many countries and constitute a environmental nuisance. New technologies have been developed to recycle these wastes into insulating materials. Several types of fines, which differ in their mineral composition, are studied herein in order to compare the resultant effects on both the physical and thermal properties of wood concretes. Thermal conductivity is measured from a full-saturated to oven-dry conditions .

The experimental results are then presented, and the ensuing analysis serves to suggest the possibility of manufacturing insulating and load-bearing materials using little energy.
Keywords: Thermal properties, waste, wood concretes.

1 Introduction

Large quantities of mineral fines, generated from operating aggregate quarries, are present in many countries. These industrial wastes are not actually being reused at the current time and could constitute a significant environmental problem. The choice has been made to recycle them by manufacturing lightweight concretes.

Previous work [1 to 3] has demonstrated this possibility through reliance on one of the following processes: the creation of cells forming a fine-cement paste (cellular concrete), or the addition of wood shavings into a fine-cement paste (wood concrete).

The materials developed can be both insulating and load-bearing, or insulating composites, depending on the specific composition. In this paper, only the weight reduction by wood aggregate will be considered.

The aim of this work is to study the comparative effects of mineral fines on wood concrete's thermal properties. When placed in a moist atmosphere, wood composites can retain water by the adsorption process. This phenomenon is highly dependent upon the matrix [4] related to its water affinity. It is well known that moisture content can particularly affect thermal performances. Thermal conductivity will be measured from fully-saturated to an oven-dry conditions.

2 Materials and experimental program

2.1 Raw materials

The selected mineral fines are presented in Table 1. They have been collected from mud after drying at 105°C for 24 hours in a drying oven, the waste is hence in a ground form. The powders are then maintained in a dry cell.

Fine	Origin	Main minerals components
GR	mud resulting from sawing operations on massive granite rock.	feldspar, mica and quartz
SA	mud resulting from the exploitation of sandstone quarry by washing aggregates obtained by crushing.	quartz
C1	mud resulting from the exploitation of alluvial aggregates by washing.	kaolinite and ~5% of quartz
C2	mud resulting from the exploitation of alluvial aggregates by washing.	kaolinite and ~75 % of quartz

Table 1: Mineral fines

The grain size distribution curves, obtained by a laser granulometry technique, are displayed in Figure 1.

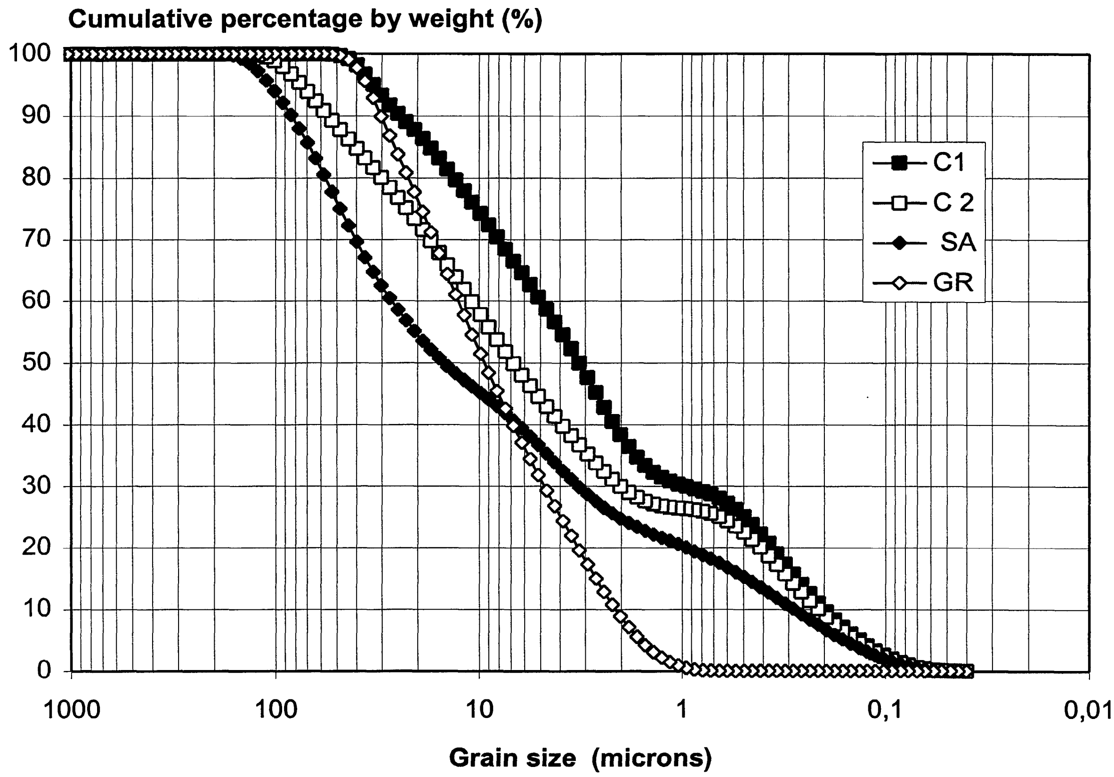

Fig 1: Grain size distribution curves of studied fine minerals

The other physical characteristics are shown in Table 2. The dry densities have been determined by pycnometry [1].

Fine	Dry density (kg/dm^3)	Thermal conductivity (W/mK)
GR	2.64	2.58
SA	2.62	4.72
C1	2.62	2.35
C2	2.65	3.62

Table 2: Some physical characteristics of studied fine minerals

The thermal conductivities of the powders have been measured by the method recently developed by A. Bouguerra [5]. It should be noted that all of the selected fines in granular form are heat conductors in comparison with ground wood (λ ~,15W/mK

[5]), in particular the sandstone fine (λ = 4.72 W/mK). The proportions of quartz seem to be a factor of importance.

The characteristics of the stabilized wood aggregates are: apparent density: 255 kg/m^3, moisture content : 9 %, water absorption, by weight : 120 %.

The cement used to ensure the chemical stabilization is the CPA CEM I 52.5, in accordance with the European Standard EN 196-1.

2.2 Formulation of the composite materials

All of the lightweight concretes studied have been produced with the same dry-weighted mix.

The proportions used, by weight, were: cement : 25 %; mineral fine: 50 %; and wood aggregate: 25 %

The workable mixing water content was calculated using the empirical relationship in [1]:

$$W = W_1C + W_2F + W_3W_A$$

Where: C = cement weight (kg); F = fine mineral weight (kg); W_A = wood aggregate weight (kg); W_1, W_2 and W_3 = experimental coefficients relative to the cement, fine mineral and wood-treated aggregates, respectively. These have been determined such that the mixture with water exhibits a normal consistency. W_1 = 0.35 in accordance with A.Moslemi [6] and K.Alrim [1].

W_2 has been determined experimentally by the authors: W_2 = 0.45 for granite and sandstone powders; W_2 = 0.70 for clay powders; and W_3 = 0.80 in accordance with A.Bouguerra [5].

Dry cement and mineral fines were mixed in a laboratory mixing machine, in accordance with the French Standard NFP 15437 before adding the wood aggregates. Water was then gradually added when the dry mixture became homogeneous. Afterwards, the concrete was moulded and placed into a controlled-temperature and moistness cell (Θ = 20°C and HR = 90%), in accordance with NFP 15401. Following removal, the samples were maintained in the cell and cured for 28 days. Then, those samples intented for density and mechanical characteristic measurements were put in a drying oven (105°C) up until a constant weight was achieved. Those samples intented for the thermohygrometric measurements were immersed for 28 days into distilled water for curing. The saturation (constant weight) was obtained before testing.

The internal dimensions of the molds used in this investigation were 100 mm x 100 mm x 100 mm.

For measuring the thermal conductivities of specimens at various water contents, the line source method [7,8] was employed. The measurements were performed at 20°C. A series of water contents, from a fully saturated to an oven-dry condition was generated by progressive drying in a microwave oven. This technique insures a homogeneous distribution of the water inside the specimens [9]. The specimens are preliminarily placed into plastic bags and sealed by welding. Then they are packed inside a climate - controlled cell until the temperature equilibrium has been reached.

3. Experimental results

3.1 Physicomechanical characteristics

Table 3 provides the characteristics of the composites developed. It can be observed that the dependence of compressive strength on dry density has not been well established when the fine minerals used are basically different. In spite of its higher density, granite displays a lower compressive strength. For equal densities, the compressive strength of the sandstone composite is more than twice that of the clayey composite. The clayey composite C_2 displays a density that's lower than the composite C_1, yet its compressive strength is higher.

These results serve to demonstrate the significance of the findings.

Fine mineral employed	Density	Compressive strength(MPa)
GR	770	3,3
SA	730	4,6
C1	740	2,0
C2	700	2,2

Table 3: Physicomechanical characteristics of the composites

3.2 Thermal conductivity

Temperature and moisture content are among the most important factors influencing the thermal conductivity of lightweight concretes. In this work, the measured results of the dependence of thermal conductivity on the moisture content of the lightweight fine concretes produced herein have been analyzed. Thermal conductivity measurements were carried out at different water contents of the samples, yet always at the same temperature: 20°C. Figure 2 shows the experimental results obtained.

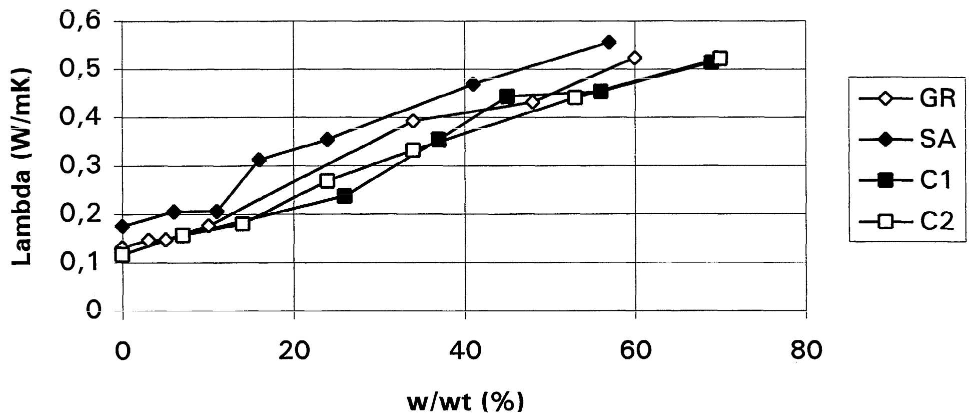

Fig 2: Effect of the water content on thermal conductivity for the various lightweight concretes.

In a dry state, the conductivity of sandstone is the highest, while that of the other composites remains very close.

This behaviour, with the increase in moistners, is also the same despite the values of λ, which are always higher in the case of sandstone. Within the limits of experimental error, no difference between the two clayey composites studied is detected.

A comparison between experimental and theoretical values reveals the recommended relationship of the American Concrete Institute [10] has been obtained:

$$\lambda = \lambda_0 \left[1 + K\left(\frac{w}{wt}\%\right)\right]$$

λ_0: coefficient of thermal conductivity at the dry condition or at w/wt = 0 (W/mK)
K = 0.06 for lightweight concretes and 0.09 for normal weight concretes
w/wt : water content.

The results are listed in Table 4.

Fine mineral employed	w/wt (%)	λ_0 (W/mK)	λ_{th} (W/mK)	λ_{ex} (W/mK)	difference/λ_{th} (%)
	60		0.602	0.523	15
GR	34	0.131	0.398	0.392	1.5
	5		0.170	0.147	15.6
	3		0.154	0.146	5.5
	41		0.605	0.469	29
SA	24	0.175	0.427	0.354	20.6
	16		0.343	0.312	9.9
	6		0.238	0.205	16.1
	56		0.510	0.454	12.3
C1	45	0.117	0.433	0.444	-2.5
	37		0.376	0.354	6.2
	7		0.166	0.157	5.7
	53		0.489	0.441	10.9
C2	34	0.117	0.356	0.332	7.2
	24		0.285	0.268	6.3
	7		0.166	0.156	6.4

Table 4: Theoritical and experimental data of thermal conductivity

The theoretical values are, in the majority of cases, greater than the experimental values. Except in the case of sandstone, this difference is even more significant as the moisture content increases. This can be explained by the results obtained by A. Bouguerra. He has shown that in the case of saturation by capillarity, the water localizes essentially in the matrix. The wood aggregates play the role of cutting off the capillarity. This is due to the double porosity of the wood concretes: macroporosity, provided by the aggregates, and the microporosity of the matrix. This phenomenon is more distinct in the case of sandstone. At the present time, we do not possess sufficient explanatory elements, nonetheless, it should be pointed out that the fine mineral actually contains the largest-sized grains.

4 Conclusion

On the basis of these test results, the following set of conclusions can be drawn.

The mineralogical composition of the studied fine exerts an influence on the physical properties of the lightweight concrete, yet this influence would require entering into too great of a level of detail .

The main purpose of this work was to evaluate the possibility of recycling mineral industrial wastes in lightweight, low environmental-impact materials, which necessitated both manufacturing by means of technologies enabling low-energy consumption and advantageous thermal characteristics. The experimental results have shown that the designed lightweight fine concretes do possess a high insulating capacity. The coefficient of thermal conductivity in the dry condition is, in any event, less than 0.2 W/mK for a density near 0,7. Its variation with respect to water content is overall in good agreement with the ACI recommendation. The mechanical performance is indeed sufficient to take into consideration the design of insulating or both insulating and load-bearing blocks.

References

1. Al.Rim, K. (1995) *Etude de l'influence de différents facteurs d'allégement des matériaux argileux : le Béton Argileux Léger. Généralisation à d'autres fines de roches et application à la conception d'éléments de construction.*, Thèse de doctorat de l'Université de Rennes I, Rennes.
2. Queneudec, M., Legarrec, M.J., AlRim, K., And Bouguerra, A. (1996) *Concrete for Environment Enhancement and Protection,* E&FN Spon, London.
3. AlRim, K., Ruzicka, M., Legarrec , M.J. And Queneudec, M. (1996) Valorisation de fines minérales industrielles. *Revue Déchets. Sciences et techniques,* No. 1., pp 37-40.
4. Ledhem, A. (1997) *Contribution à l'étude d'un béton de bois. Mise au point d'un procédé de minimisation des variations dimensionneles d'un composite argile-ciment-bois.*, Thèse de doctorat de l' INSA de Lyon, Rennes France.
5. Bouguerra, A.(1997) *Etude d'un procédé de valorisation de déchets argileux: comportement hygrothermique des matériaux élaborés.* Thèse de doctorat de l'INSA de Lyon., Rennes France.
6. Moslemi, A.And Pfister, S.C. (1987) The influence of cement/wood ratio and cement type on bending strength and dimensional stability of wood-cement composite panels. *Wood and fiber science,* Vol 19, No. 2. pp 165-75.
7. Hladik, J. (1990) *Métrologie des propriétés thermophysiques des matériaux,* Ed Masson, Paris.
8. Laurent, J.P.(1992) Sonde à choc thermique monotige. *Communication privée LTHE.*

9. Horton, R., Wierence, J.P. And Nielson, D.R. (19982) A rapid technique for obtaining uniform water content distributions in unsatured soil columns. *Soil science,* Vol. 133, No. 6. pp 397-9.
10. (1983) *Manual of concrete practice.*, ACI 213. R-79. Part 1.

Lightweight clay-based concretes formulated with wood aggregates : hygrothermal behaviour

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Abstract :
The authors have developed technologies to recycle clay waste as insulating materials. The clay waste used in this work is mainly composed of kaolinite. The weight reduction is obtained by using wood aggregates.

This paper gives the influence of therrnohygrometric conditions on thermal performances of clayey concrete lightened by wood aggregates.
In order to determine the thermal conductivity and to reduce the water migration effects, a transient « Line Source Method » was used. The rate of saturation, expressed as the ratio of the volume content of water to the total porosity ranges from 0 to 1. The temperature range (0-60°C) covers the majority of thermal conditions in which the material is used. Thermal conductivity curves are given for different weight percentages of wood aggregates (0, 25, 30, 40, 50%). The influence of temperature, rate of saturation and wood aggregates content on mass transfer is analysed.

It can be observed that for temperatures below 20°C, the values obtained are very close. The deviation is greater as the rate of saturation increases and as the wood aggregates content increases. The maximum value reached for the thermal conductivity, λ decreases as the wood content increases. For temperatures above 20°C, the experimental curves have a tendency to diverge. This effect is even more-pronounced as the wood content rises. The phenomenon of evaporation-condensation is thus not encountered at temperatures lower than 20°C. For higher temperatures, the mechanism of transfer by conduction through the various phases combines with a heat transfer which is largely attributable to phase changes. It would seem that wood aggregates do participate in the phenomenon of condensation-evaporation within the range of temperatures greater than the ambient temperature and that mass transfers with the aggregates are essentially made in the vapor phase. Finally, it is shown that in normal operating conditions, temperature and moisture do not considerably influence the thermal conductivity of the designed materials.
Keywords : Lightweight concrete, thermal conductivity, thermohygrometric conditions

1 Introduction

Over the past quarter century, developing countries have been subjected to major demographic transformations, thereby necessitating a policy approach that accommodates exponential urban growth rates. In light of the deteriorating economic conditions often encountered, one recommended solution is to utilize local resources and to transform them into both technically- and economically-competitive materials which meet the requirements of a population in the throes of complete cultural evolution. Among such local materials, clay and wood are quite often present.

Furthermore, the industrialized nations are confronted with the problem of the wastes they produce. For example, in the western part of France, deposits of marine sand fossils from the end of the tertiary era have been in great demand. Sands being used currently contain a sizable clayey fraction that must be eliminated by washing. Residues from operations represent a volume which can only continue to increase.

Our objective herein has thus been two-fold: to reuse the by-products from industrial operations, and to develop techniques for using local materials.

Awareness of environmental quality issues has led to many of the insulators currently on the market being considered as pollutants, from the standpoint of either their manufacturing process or the eventual building site wastes generated. The approach our team has been pursing over the past several years is therefore to transform these clayey wastes into lightweight environmental impact-resistant insulating materials. In order to accomplish this, various techniques have been employed: the creation of a cellular structure, or weight reduction by the introduction of lightened aggregates. For the former, «cellscan» can be created by a either chemical reaction [1,2] or by entraining air [1, 3 to 6]. For the work presented herein, it is the weight reduction by wood aggregates [1, 7 to 13] which is. This technique does in fact make it possible to reuse the wastes from two types of industrial domains. Moreover, wood and clay are two widespread local resources in many developing countries.

Nevertheless, the simultaneous presence of clay and wood in the hardened materials can raise concerns of an increased sensitivity to water, which would serve to decrease the composite's thermal performance. A study of conductivity, in relation to both temperature and humidity, has thus been conducted.

2 Materials and experimental conditions

The cement product is a CPA-CEMI 52.5 (EN 196-1) type cement currently obtained from Lafarge industry, whereas, the clay waste used in this work is mainly composed of kaolinite [12, 14]. The particle analysis shows that 55% the particles are under $2\mu m$ and the longer diameters are of $70\mu m$. However the real limon part ($2\mu m<\phi<70\mu m$) is certainly overestimated since the separation of the clay particles by the operator is made by leaching with addition of a floculating agent.The absolute density is 2.65 and Atterberg limits are $W_L=48\%$, $W_P=36\%$, $I_P=12\%$. The thermal conductivity of the powder is 3.45 W/m.K [12].

Wooden aggregates are derived from pine waste and are stabilized by thermal processing and mineralization. The thermophysical properties are : bulk density = 255kg/m^3, moisture content = 9%, water absorption = 120%, thermal conductivity = 0,07W/m.K, thermal conductivity of ground wooden aggregates = 1.15W/m.K

The principle of weight reduction by using wooden aggregates has previously been described by Al-Rim [1]. The mixing machine conforms to standard EN-196-1. In the first step, dry waste and cement are introduced in the mixing machine and mixed in a dry state before wooden aggregates are added. Water is then gradually added to the dry mix. The water content is calculated using the expression : $W=0.35*C+W_f*A+1.5*B$ [1] where C, A, and B are the weight of cement, clay, and wooden aggregates respectively. W_f is the amount of water determined so that the mixture with water has a normal consistency (f=1 850Pa).

The concrete is then poured into moulds and placed in a controlled temperature and moisture cell (Temp.=20°C, RH=90%) in accordance with standard NF P 15401. After removal, the samples are maintained in a drying oven (70°C) until a constant weight is achieved before testing.

Table 1 gives the variations of dry density and total porosity versus the % of wooden aggregates, for the mix : cement = 20%, clay+wood aggregates=80%.

Apparent density and total porosity have been determined by mercury intrusion porosimetry.

Table 1: Wooden aggregates proportions, apparent density and total porosity of studied materials

% wooden aggregates	apparent density	total porosity
0	1.28	48.5
25	0.91	63.6
30	0.82	64.9
40	0.74	67.7
50	0.67	70.4

In order to determine the thermal conductivity and to reduce the water migration effects, a transient « Line Source Method » was used to obtain the required values in moist materials while conductivity thermal tests [12]. The measurements were performed on samples having dimensions 10x10x10cm^3. The following procedure was used in preparing the samples for laboratory measurements. A hole corresponding to the probe length (10cm) was drilled into each sample. The samples were saturated with water in accordance with the RILEM recommendation [15] and placed in sealed plastic bags. Thereafter, the samples were put in a climatic cell until temperature equilibrium was reached. Gradually, water contents were obtained as the drying process proceeded from the saturated to the dry state through progressive drying in a microwave oven. This technique insured a homogeneous distribution of water inside the material [16].

3 Experimental results and analysis

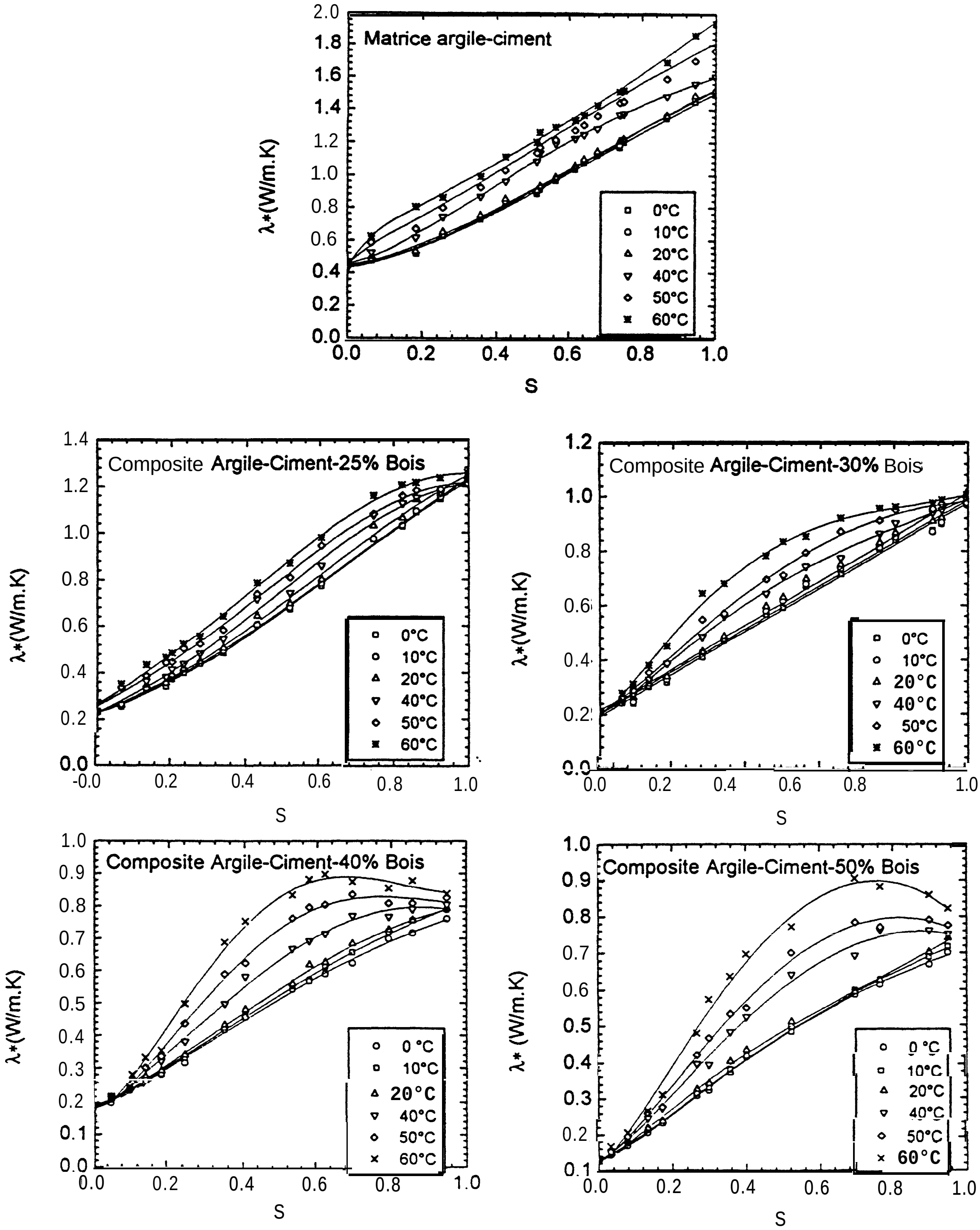
We have chosen the rate of saturation as a variable in order to determine the ratio of the volume content of water to the total porosity. The temperature range (0-60°C) covers the majority of thermal conditions in which the material is used. Thermal conductivity curves are given for different weight percentages of wood aggregate. It can be observed that for temperatures below 20°C, the values obtained are very close. The deviation is greater as the rate of saturation increases and as the wood aggregates content increases. The maximum value reached for the thermal conductivity, λ decreases as the wood content increases. For temperatures above 20°C, the experimental curves have a tendency to diverge. This effect is even more pronounced as the wood content rises. The phenomenon of evaporation-condensation is thus not encountered at temperatures lower than 20°C. For higher temperatures, the mechanism of transfer by conduction through the various phases combines with a heat transfer which is largely attributable to phase changes. Under the effect of a temperature gradient, water evaporates in warm zones of the porous middle, then distributes to cooler zones where, by condensation, it frees the latent heat of vaporization [17].

The maximum curvature observed on those curves having higher temperatures appears at a higher rate of saturation since the proportion of wood content in the composite rises (0.5 for 30% of wood, 0.7 for 50%). It therefore would seem that wood aggregates do participate in the phenomenon of condensation-evaporation within the range of temperatures greater than the ambient temperature. We have been able to observe by magnetic resonance imaging [12] that up to room temperature, in the case of saturation by capillarity, the water was essentially localized in the matrix, and that the increase in the amount of wood aggregate does not introduce any significant dispersion in the variation of the conductivity versus the rate of saturation. The vapor pressure decreases as the temperature drops ; it would thus appear that mass transfers with the aggregates are essentially made in the vapor phase. This finding is in keeping with previous work which shows that up to room temperature, in the presence of liquid water, wood aggregates act as a capillarity cut [12]. Finally, if the thermal conductivity is strongly influenced by the rate of saturation, this effect is negligible under normal working conditions (RH=65%, Temp.=20°C). Indeed, the isothermal sorption curves have shown that the mass content of water under these conditions remains in the order 3 % within the range of densities studied, i.e. for a wood aggregate content of 30 %, a rate of saturation of about 0.04.

4 Conclusion

This study has demonstrated influence of thermohydric conditions on the thermal performance of clay-based concretes lightened by wood aggregates. It has been shown

Figure1 : Effect of the temperature and water content on thermal conductivity



that under normal operating conditions, temperature and moisture do not affect the thermal conductivity of the designed materials.

This work lies within the general topic of study focused on : «High Environmental Quality Housing». It would be helpful to recall some of the other results obtained concerning this material [12]. A comparative study with other materials has shown that the thermal conductivity was very close to that of wood concrete with cementitious matrix, but that the mechanical performance was, in general, higher with an equal density despite a lower cement content (200kg / m^3 for a density of 0.8 versus 350 to 400kg / m^3). Similarly, the high value of the calorific capacity coupled with the weak thermal diffusivity make for a material that is valuable for its thermal storage characteristics despite its rather low density (1300J / kg.K and $2.3 \times 10^{-7} m^2 s^{-1}$ respectively for a density equal to 0.8). Moreover, up to room temperature, in contact with liquid water, the presence of wood aggregates tends to slow the progression of the imbibition capillary front as well as decrease the quantity of water being absorbed by the material. These results illustrate the possibility of designing technically-sound materials from clay wastes.

5 References :

1. Al-Rim, K. (1995) *Le béton argileux léger. Generalisation a d 'autres fines de roches et applications a la conception d'éléments de construction préfabriqués.* These de Doctorat de l'Université de Rennes I, Rennes, France.
2. Marmoret, L., Bouguerra, A., Alrim, K. And Queneudec, M. (1995) « Caracteristiques thermiques d'un béton argileux cellulaire : cas d'un allegement par reaction avec l'aluminium pulverulent », *Revue Générale de Thermique,* Tome 34, No 402. pp 393-400.
3. Al-Rim, K., Morteveille, M.A. And Queneudec, M. (1994) « Influence de l'addition d'un entraîneur d'air proteinique sur un melange d'argile-ciment », *Revue Internationale d 'Héliotechnique, No. 9.* pp. 36-46.
4. Al-Rim, K., Ruzicka, M. And Queneudec, M. (1995) *Conchem International Exhibition & Conference,* Ziolkowsky, H. GmgH, Augsburg.pp. 361-369.
5. Ruzicka, M., Lorin, D. And Queneudec, M. (1996) *Production Methods and Workability of Fresh Concrete,* E&FN Spon, London. pp. 495-504
6. Ruzicka, M., Dheilly, R.M. And Queneudec, M. (1997) *Conchem International Exhibition & Conference,* Ziolkowsky, H. GmgH, Augsburg.pp. 57-62
7. Bouguerra, A., Ledhem, A. And Queneudec, M. (1995) *Conchem International Exhibition & Conference,* Ziolkowsky, H. GmgH, Augsburg.pp. 483-489
8. Ledhem, A, Bouguerra, A. And Queneudec, M. (1996) « Etude de l'influence du traitement des granulats et d'ajouts matriciels sur la stabilisation dimensionnelle d'un composite ciment-bois-fines ». *Revue Marocaine de Genie Civil, No. 64.* pp. 63-67.
9. Al-Rim, K., Ledhem, A. and Queneudec, M. (1996) « Etude des paramètres de fabrication d'un béton de bois à matrice argileuse », *Materials and Structures, No.* 29. pp. 514-18.

10. Bouguerra, A., Ledhem, A., t'Kint de Roodenbeke, A. and Queneudec, M. (1996) « Incorporation de dechets argileux dans les bétons de bois : propriétés mécaniques et thermiques », *Déchets Sciences et Techniques, No 4.* pp. *44-47.*

11. Bouguerra, A., Al-Rim, J., t'Kint de Roodenbeke, A. and Queneudec, M. (1997) *Buildings and the Environment,* Centre Scientifique et Technique du Bâtiment, Paris.pp. 651-658

12. Bouguerra, A. (1997) *Contribution à I 'etude d 'un procédé de valorisation de dechets argileux : comportement hygrothermique des materiaux élaborés*. These de Doctorat de l'INSA de Lyon, Rennes, France

13. Ledhem, A. (1997) *Contribution à l 'etude d 'un béton de bois. Ise au point d'un procédé de minimisation des variations dimensinnelles d 'un composite argile-ciment- bois.* These de Doctorat de l'INSA de Lyon, Rennes, France.

14. Esteoule, J. (1970) *Contribution a l 'etude des argiles du massif armoricain.* These de Doctorat, Rennes, France.

15. Rilem CPC 11.3 (1984) « Absorption d'eau par immersion sous vide ». *Materials and structure.* Vol. 17, No.101.pp391-394

16. Horton, R., Wierenge, P.J. And Nielsen, D.R. (1982) « A rapid technique for obtaining uniform water content distributions in unsaturated soil columns ». *Soil Science,* **Vol.** 133, **No.** 6. pp 397-9.

17. Degiovanni, A. And Moyne, C. (1987) « Conductivité thermique de materiaux poreux humides : evaluation theorique et possibilite de mesure ». *International Journal of Heat and Mass Transfer,* Vol. 30, No. 11. pp. 2225-45.

A lightening process of clay-cement pastes by recycled oxblood

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Abstract:
Blood is a very powerful air-entraining agent and can be used to foam clay-cement paste. The foaming process depends on the components of concrete and can be optimized by certain additives.

This paper describes the influence of such factors on the volumic proportion of air entrained and the mechanical properties of hardened materials.
Keywords: Air entraining agent, insulating materials, lightweight concrete.

1. Introduction

Blood has been used in building materials from a long time as a means of improving the workability and impermeability. Powdered blood has first been added to concrete in the Soviet Union during the 1970's. In France, Venuat M. [1] has shown that a small quantity of powdered blood is sufficient to entrain 5 to 25% air, the air bubbles are small, well-distributed and separated from one another.

The studied material is a clay-cement mixture foamed by stabilized haemoglobin stem from the separation of animal blood. The clayey part is presently an unused by-product of the utilized clay-containing sand. Over the last few years, the authors' studies have been focused on transforming this by-product into low environmental-impact insulating materials [2 to 16].

The foaming process is very complex, it must be optimized with respect to the features of workability and mechanical performances of the hardened concrete criteria.

2 Materials and experimental conditions

The clay waste (A) used in this work is mainly composed of kaolinite [14]. The granulary analysis show that the part under 2 μm is 55 % and the higher diameter is 70 μm. However the real limon part (2 $\mu m < \phi < 70\ \mu m$) is certainly overestimated because the separation of the clay part by the operator is made by leaching with addition of flocking agent. The absolute density is 2.65 and Atterberg limits are $W_L = 48\ \%$, $W_P = 36\ \%$, $I_P = 12\ \%$.

The cement (C) is a CPA - CEM I 52.5 (EN 196-l).

The air entraining agent (H) is oxblood haemoglobin powdered and stabilized.

The mixing water (E) is drinking water taken from the public water supply network at a temperature of 20 ± 2 °C and a pH = 7.75 before adding NaOH and HCl into normal solution.

The components are first dry-mixed during 2 minutes in a mixer which is usally used for normalised mortar (EN 196-1).

Next, water is gradually added until obtaining a homogeneous mixture. The haemoglobin powder is then added and the mixing is extended at 120 t / min during 30 minutes.

The equipment used to measure the apparent viscosity is a Brookfield DV III rheometer .The volume of the enclosed air is determined with the help of an aerometer for mortar (EN 413 - 2).

3 Experimental results

3.1 The influence of the components on the rheological characteristics

3.1.1 Cement

With the quantity of clay being held constant, the influence of the cement is studied in the presence or absence of haemoglobin. Results have been plotted in Figurel. It can be observed that in the absence of haemoglobin, adding cement serves to increase the viscosity.

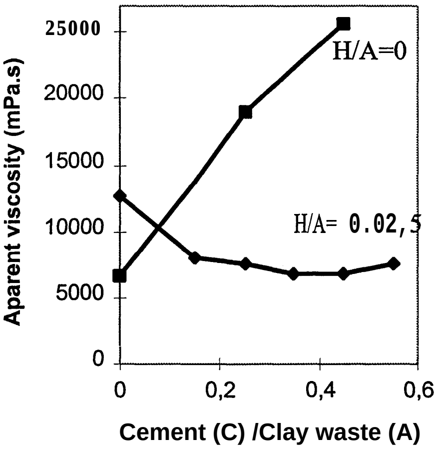


Figure 1 : Influence of the cement on the apparent viscosity (time of shearing : 0.5 min, ϖ = 50t/min, E/A = 0.75)

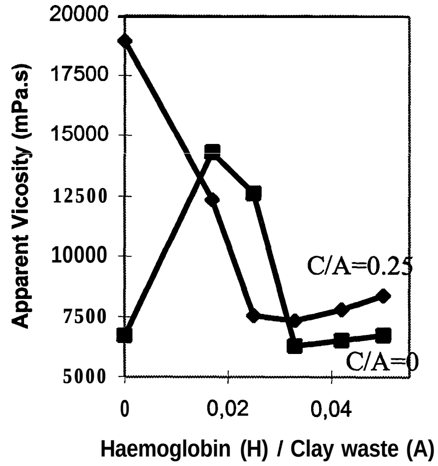


Figure 2 : Influence of the haemoglobin on the apparent viscosity (time of shearing : 0.5 min, ϖ = 50t/min, E/A = 0.75)

In the presence of haemoglobin in very weak proportions, a clearly greater viscosity, approximately double of that without cement can be noticed. The presence of haemoglobin would therefore have a rigidifying effect on its own on clay grouts. In contrast, as the quantity of cement increases, the viscosity of the foamed mix decreases; for a ratio C /A=0.35, the viscosity of a grout of clay obtained with a ratio E/A=0.75 can then be found. An analysis of the densities shows that the volume of foam tends to follow the same type of law.

The slight increase in viscosity beyond a C /A ratio = 0.45 can be explained by the consumption of a greater amount of water in connection with the hydration of the cement.

3.1.2 Haemoglobin

The influence, of the percentage of haemoglobin on the viscosity, has also been examined in the presence or absence of cement. Results are plotted in Figure 2, for C/A ratios of 0.25 and 0. In the presence of cement, the apparent viscosity, which is high for a mix without any haemoglobin, decreases as the ratio H/A increases. Beyond an H/A value of 0.033, a slight increase in viscosity can be observed, along with poorer flowability. In the absence of cement, no foam production takes place, with the mix of clay and water remaining relatively fluid while the addition of a small quantity of haemoglobin (H/A=0.017) increases suddenly the viscosity. It is difficult to conceive that increasing the fine part of 1.7% could nearly triple the viscosity of the mixture despite the very high specific surface of the added fraction. It could have therefore be assumed that a clay-haemoglobin interaction mechanism is responsible for this phenomenon, which does not appear in the presence of cement. As the quantity of haemoglobin continues to increase, a significant drop in the viscosity is to be noted, a long with a light foam production which can be attributed to the mechanical agitation of a very fluid mix.

3.1.3 Water

As the increase in the quantity of mixing water rises, the decrease in viscosity becomes more pronounced and the volume of foam rises. Nevertheless, the display is not necessarily improved.

3.2 Study of the air-entraining process

Several factors are able to modify the amount of entrained air: the proportion and nature of basic constituents, various chemical processes, temperature, characteristics of the mixing process, etc.

3.2.1 Influence of the pH of the mixing water

A comparative study was carried out on a pure clay paste (A + E), supplemented with either treated haemoglobin (A + E + H) or cement plus haemoglobin (A + E + C + H)

Figure 3 displays the evolution of the amount of enclosed air by adding H^+ and **OH'** ions

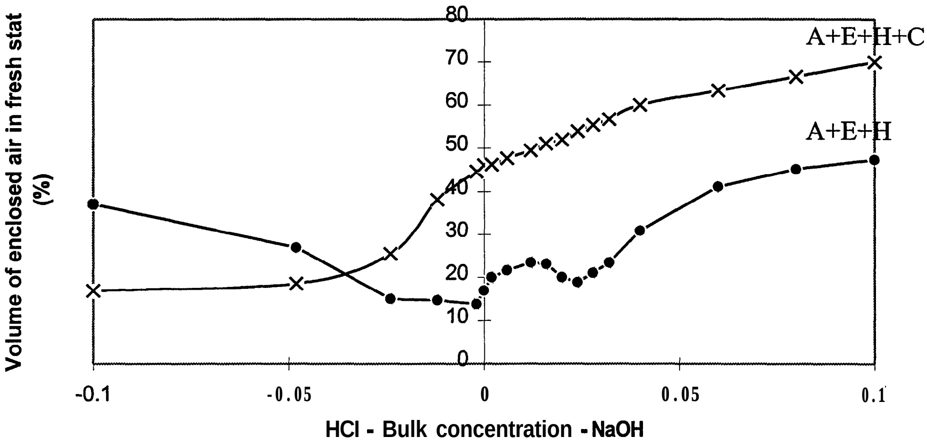


Figure 3 : Influence of the concentration of the mixing water, on the volume of the enclosed air

The entrained quantity of air is greater in the presence of cement for a water with no addition of either H^+ or OH- ions. In the presence of cement, the amount of enclosed air steadily increases from 45 to 70 % in the case of bulk concentrations of sodium hydroxide varying from 0 to 9 %. In contrast, this amount first decreases in a steady fashion when the acid concentration increases and then stabilises at 20 % as the acid concentration approaches 4 %. In the absence of cement, the inverse would apply during the addition of air, with the volume of entrained air increasing from 10 to 40 %. During the addition of sodium hydroxide, air entraining is also facilitated except when the concentration turns out to equal approximately 2 %. Measurements of the fresh mixture density [17]serve to corroborate these remarks, however, such measurements have not yet been interpreted.

Previous works [17] has shown that, in the absence of cement, the lightening and the moulding can be indiscriminately promoted by either H^+ or OH- ions. In contrast, in the presence of cement, if air entraining could be enhanced by introducing OH- ions, no improvement in fluidity would actually be experienced. The addition of H^+ ions is therefore entirely unfavourable.

3.2.2 Influence of the binder nature

The entraining of air seems to be closely linked to the presence of cement in the material. The question thereby raised whether or not the phenomenon is due to the composition of the cement wherein the medium's pH level is increased by the cement. Measures of the amount of entrained air in the absence of clay, have thus been performed for four binders: cement CPA, aluminous cement, hydraulic lime, and aerial lime. In all four cases, the pH is high. The amount of entrained air for these different binders are plotted in Figure 4.

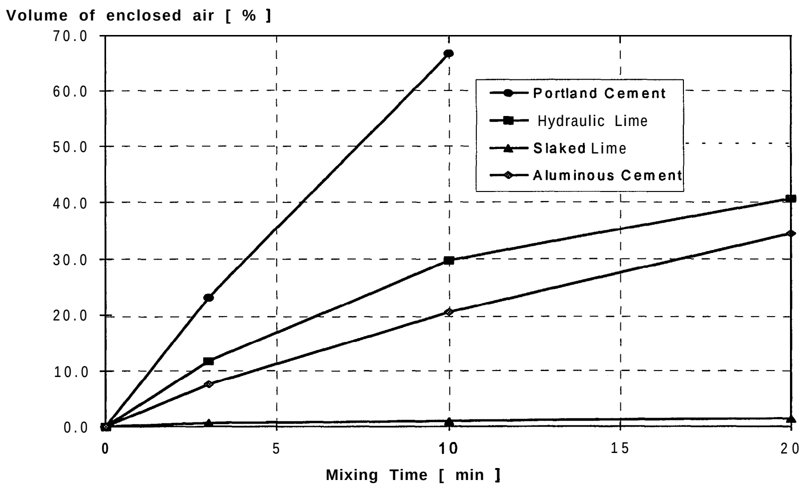


Figure 4 : Volume of enclosed air as a function of the binder and mixing time

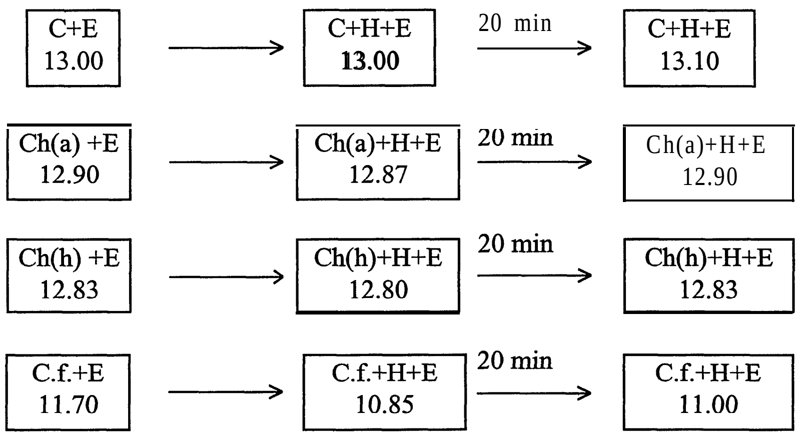
It can be observed that the pH level does not suffice in explaining the foam's production. Indeed, the grout derived from a base of aerial lime possesses a pH closer to that of cement grout (before and after mixing) (Figures); however, no air entraining effect is present. The nature of the binder would therefore seem therefore to play an important role. Nevertheless, this phenomenon as of this day has still not been completely clarified.

3.3 Influence of the mixing process

It has previously been shown that the presence of soda always favours the entraining of air. We will therefore use a treated water in order to study the mixing. Figure 6 displays the evolution in the apparent viscosity with respect to mixing time. This relationship is indeed not regular. Moreover, observation to the naked eye allows us to observe that at 0 min of mixing, the mix exhibits the form of a plastic paste. At between 5 and 10 min, a rather thick foam begins to appear, which is relatively mobile, while at between 20 and 30mn, the foam becomes very voluminous and immobile.

We have thus attempted to improve the workability. After mixing for a given period, the foamed material is left to rest for 15min. Mixing is then repeated for another 20 seconds. Observation to the naked eye reveals that the fluidity has been clearly improved, yet this is not visible on the viscosity curve (Figure 7).

The study of workability shows that as opposed to the foam obtained after the standard mixing, the « remixed foam » flows more easily. This improvement is probably due to a change in the foam's structure.



Ch(a) : Slaked lime, Ch(h) : hydraulic lime

Figure 5 : Influence of the nature of the binder on the pH, E=7.75 et H+E=7.83

3.4 Mechanical strength

Figure 8 shows the evolution of the compressive strength with respect to density. The lightening due to the presence of the soda served to improve the mechanical strength characteristics beyond those of the non lightened material.

4 Conclusion

The general purpose of this study was to recycle clayey fillers stemming from aggregate quarrying activities by producing low environmental-impact insulating materials. The lightening step was performed by a proteinic air-entraining agent, which was a reused industrial waste. From a study of the components' influence, it can be proven that the presence of cement is a major factor in the foaming process. The amount of entrained air can be modified by addition of H^+ or OH- ions. This would depend on the binder composition. A mixing process has been developed in order to improve workability and facilitate moulding. The mechanical performance obtained is satisfactory.

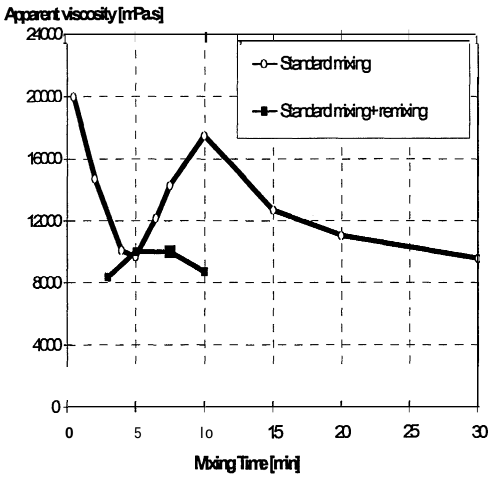


Figure 6 : Evolution of the apparent viscosity as a function of the mixing time

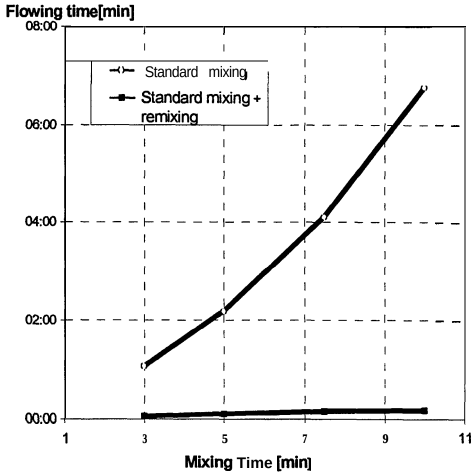


Figure 7 : Workability as a function of the mixing time

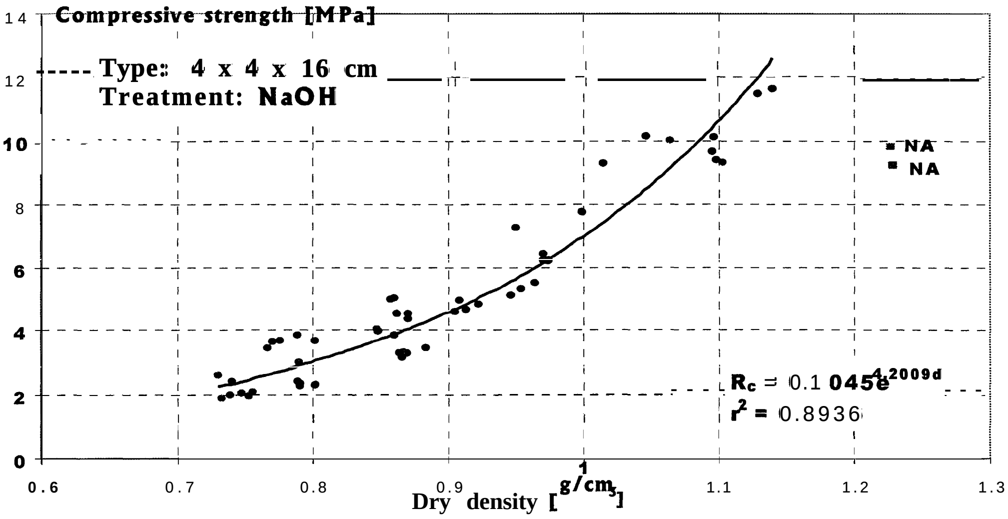


Figure 8 : Compressiv strength versus dry density

References

1. Venuat, M. (1984) *Adjuvants et traitements : Techniques modernes d'amélioration des ouvrages en b&on,* First Edition by the author.
2. Al.Rim, K., Queneudec, M., t'Kint de Roodenbeke, A And Decamps, E.A. (1992) Congrés Mondial du Bâtiment - Montreal.
3. Al.Rim, K., Morteveille M.A.And Queneudec, M. (1994) Influence de l'addition d'un entraîneur d'air proteinique sur un melange d'argile-ciment. *Revue Internationale d'Héliotechnique,* N°. *9* pp. 26-36.
4. Al.Rim, K., L'Haridon, B. And Queneudec, M.(1994) Application des differentes méthodes d'allegement des argiles à la prefabrication d'éléments de construction. *Revue Internationale d'Héliotechnique,* N° 10 pp 33 - 47.

5. Al.Rim, IS. (1995) *Etude de l 'influence de différents facteurs d 'allegement des matériaux argileux : le Béton Argileux Léger. Generalisation a d 'autres fines de roches et application à la conception d'éléments de construction préfabriqués*, These de doctorat de l'Université de Rennes I, Rennes.
6. Marmoret, L., Bouguerra, A., Al.Rim, K. And Queneudec, M. (1995) Caracteristiques thermiques d'un béton argileux cellulaire : cas d'un allegement par reaction avec l'aluminium pulverulent. *Revue Générale de Thermique*, Vol 34 N° 402 pp 395- 400.
7. Bouguerra , A., Ledhem, A. And Queneudec, M. (1995) *ConChem International Exhibition & Conference*, Ziolkowsky, H. GmgH, Augsburg.
8. Al.Rim, K., Ruzicka, M. And Queneudec, M. (1995)_ *ConChem International Exhibition & Conference*, Ziolkowsky, H. GmgH, Augsburg.
9. Al.Rim, K., Ruzicka, M.J., Le Garrec And Queneudec, M., *Dechets Sciences et techniques, No.* 1. pp.37-40.
10. Ledhem, A., Bouguerra, A. And Queneudec, M. (1996) Etude de l'influence du traitement des granulats et d'ajouts matriciels sur la stabilisation dimensionnelle d'un composite argile-ciment-bois. *Revue Marocaine du Genie Civil, No. 64.* pp63-68.
11. Al.Rim,, K., Ledhem, A. And Queneudec, M. (1996) Etudes des paramètres de fabrication d'un béton de bois à matrice argileuse. *Materials and Structures,* Vol. 29, No. 192. pp 514-18.
12. Ruzicka, M., Lorin, D. And Queneudec, M. (1996) *Production Methods and Workability of Fresh Concrete.,* E&FN SPON, London
13. Bouguerra, A., Ledhem, A., t'Kint de Roodenbeke, A. And. Queneudec, M. (1996) Incorporation de dechets argileux dans les bétons de bois. Propriétés mécaniques et thermiques. *Dechets Sciences et Techniques, No.* 4., pp 44-7.
14. Bouguerra, A. (1997) *Contribution à l 'etude d 'un procédé de valorisation de dechets argileux : comprtement hygrothermique des matériaux élaborés.*, These de Doctorat de l'INSA de Lyon, Rennes.
15. Bouguerra, A., Al.Rim, K., t'Kint de Roodenbeke A. And Queneudec, M. (1997) *Buildings and the Environment,* Centre Scientifique et Technique du Batiment, Paris
16. Ledhem, A. (1997) *Contribution a l 'etude d 'un béton de bois. Mise au point d 'un procédé de minimisation des variations dimensionneles d 'un composite argile-ciment-bois.,* These de doctorat de 1' INSA de Lyon, Rennes.
17. Ruzicka, M., Dheilly, R.M. And Queneudec, M. (1997) *ConChem International Exhibition & Conference,* Ziolkowsky, H. GmgH, Augsburg.

A RC filler slab with non-autoclaved cellular concrete blocks for sustainable Construction

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Abstract
Flyash is a major industrial waste which pollutes the atmosphere. The thermal plants in India will generate about 100 million tonnes of flyash per year by the turn of the century. Acres of usable land are wasted for dumping of ash. Transportation poses handling problems; besides, the proposition is uneconomical. In this context, utilisation of this waste material in building construction will go a long way in solving its disposal problem. Towards this end, a technology has been developed at the Central Building Research Institute (CBRI), Roorkee, India, to construct reinforced floor/roof slab with non-autoclaved cellular concrete filler blocks cast with flyash, lime, cement and a foaming agent. Autoclaved cellular concrete blocks are being used in the building industry to some extent in India. But as they require autoclaving for the production, they are costly. Hence non-autoclaved units have been developed with a suitable proportion of the constituents. The blocks are of size 260 x 560 mm, tapering down to 250 x 550 mm and are 110 mm thick. The floor/roof slab is cast with cement concrete of grade Ml 5 with these blocks as fillers. Reinforcement bars are provided in two perpendicular directions in the space between the blocks. Room size filler slabs were tested for their structural and functional performance at CBRI. Deflection recovery tests, failure load tests and impact load tests were conducted. Functional properties like thermal performance index, sound absorption coefficient, leak proofness etc. were also studied. The paper describes the experimental studies and results.

Housing shortage is a common problem in most of the developing countries and there is a need for appropriate construction techniques which are economical and affordable. The requirement of housing in India by the turn of the centuary is expected to be 39 million units and even if 10 percent of the construction is done with this technique, it will result in utilisation of 10 million tonnes of flyash. Compared to conventional insitu RC slab, this technique is economical and will result in saving of cement and steel and is an ideal step towards generation of affordable housing, for developing countries.
Keywords: Construction, filler slab, flyash, non-autoclaved cellular concrete blocks.

1 Introduction

Flyash is a major industrial waste and large scale use of this material in building construction will go a long way in solving the disposal problem of this pollutant material. Hence filler slab technology for flooring/roofing has been developed at CBRI. In this technique, the slab is cast with non-autoclaved cellular concrete filler blocks, produced from flyash, lime, cement and a foaming agent. Utilisation of flyash in large quantities for the production of the blocks is an advantage and also the technique results in saving of cement and steel and cost of construction, compared to conventional reinforced concrete slab for floor and roof.

2 Construction technique

The floor/roof consists of a cast insitu RC filler slab with non-autoclaved cellular concrete filler blocks as shown in Fig. 1. The filler blocks are 110 mm thick and 260 x 560 mm at top tapering down to 250 x 550 mm at bottom. The slab is cast with cement concrete of grade M15. Spanning in two perpendicular directions, the slab can be designed as a grid with compression taken by the deck concrete at top and tension taken by the reinforcement at the bottom in the rib portion. The cellular concrete blocks act as non-structural fillers. The technique can be adopted for floor/roof in single and multistoreyed residential and other types of buildings. Conventional roof/floor finish could be laid above the filler slab. Ceiling plaster could be avoided in low cost constructions and also where better acoustic performance is called for. In other situations the ceiling may be plastered.

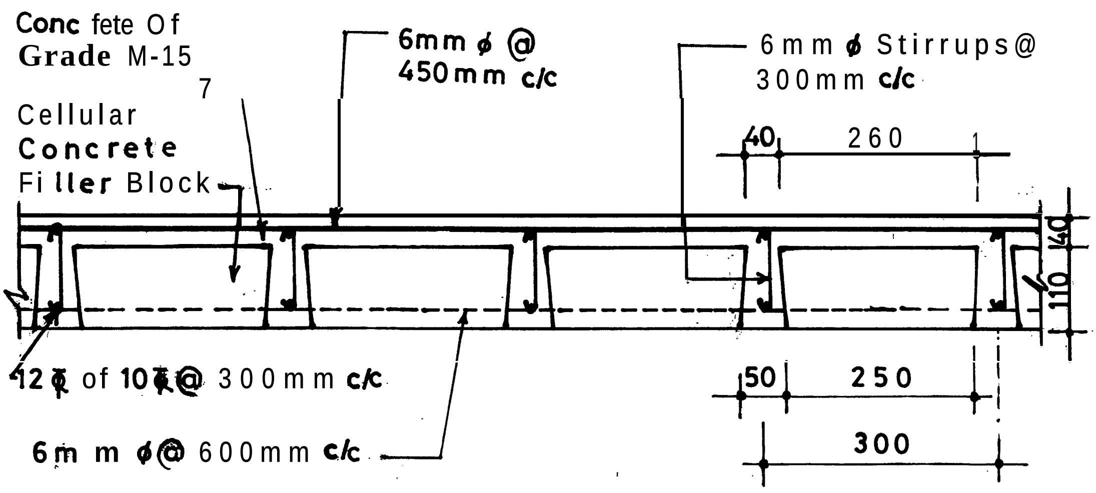

Fig. 1 RC filler slab (section)

3 Cellular concrete blocks

Autoclaved cellular concrete blocks are being used in the building industry in India to some extent. But as they require autoclaving for their production, they are costly. To make it economical, non-autoclaved cellular concrete blocks have been developed using flyash, cement, lime and a foaming agent. Several mix proportions were tried before arriving at a suitable mix from considerations of density and strength to withstand the stresses to which the blocks are subjected to, during construction. Quantities of materials required per cu.m of concrete for the selected mix are given below :

Cement	: 140 kg
Lime	: 35 kg
Flyash	: 528 kg
Foaming agent (Aluminium powder)	: 0.32 kg

Since flyash is available in fine particle state, it requires no further grinding. Cement [1, 2] lime [3] and flyash [4], as per the proportion mentioned above, are wet mixed in a high speed mixer to a homogeneous slurry. Aluminium powder is then added and mixed thoroughly. Hydrogen gas liberated by the aluminium powder, due to its reaction with lime,aerates the slurry. The slurry is then poured into steel moulds of size 560 x 260 mm tapering to 550 x 250 mm in plan and having a height of 110 mm. The slurry is filled only to three fourth the depth of the mould. Due to aeration, it rises upto the top or slightly above the top of the mould. Setting takes place in 10 to 12 hours in tropical climate. After setting, the part of the concrete above the mould is trimmed off and demoulding is done 24 hours after casting. The blocks are kept at casting platform for 2 days and after they have attained strength to withstand handling stresses, they are shifted to curing yard and cured under wet gunny bags for 14 days. The blocks are then allowed to air dry, for another 14 days.

4 Construction of floor/roof slab

The reinforcing bars for the bottom of the slab in two perpendicular directions are tied together and placed over the shuttering with concrete cover blocks tied to them. Cellular concrete blocks are then assembled over the shuttering in the space between reinforcement bars, leaving a gap of 40 mm between adjacent blocks in the two perpendicular directions. The blocks are then aligned properly and reinforcement cage for the flange portion is tied and placed over the cellular concrete blocks (Fig.2). Concrete cover blocks shall be tied to the reinforcement in the flange also to ensure required cover. The blocks are sprinkled with water repeatedly so that the surface is at a near saturation point. This is necessary to ensure that the blocks do not absorb excessive quantity of water from the fresh concrete. Concrete of grade M 15, made of coarse aggregate of maximum size 12 mm, is then laid in the space between the blocks and compacted using a needle vibrator. Immediately, the flange concrete above the filler blocks is laid and compacted using plate vibrator. The top surface is then finished properly. A camber of 1 in 250 may be provided to the shuttering in case of floor slab so that the ceiling of floor is level after removal of shuttering. In case of roof, a slope of 1 in 60 may be provided to the shuttering so that the top of the roof will have a slope of about 1 in 80 after the shuttering is removed. The concrete shall be cured for 14 days byponding water over it. The shuttering shall be removed after that. The ceiling may be plastered one month after removal of shuttering.

Fig. 2 RC filler slab under construction

5 Structural design

The filler slab may be analyzed as a two way spanning grid slab. The midspan section is designed as a T-beam with cast-in-situ concrete of flange taking compression and reinforcement at the bottom of the slab in the web portion taking tension. In case of continuous slab, the support section is designed as doubly reinforced rectangular beam with the width ofbeam equal to the thickness ofweb. To control deflection, the span/depth ratios have been considered as per the relevant Indian Standard Code of Practice. A 150 mm thick slab can span upto 3.6 m in case of simply supported and upto 4.5 m in case of continuous spans. In case of larger spans, a higher slab thickness is called for the control of deflection. In this case, filler blocks of thickness more than 110 mm may be used.

6 Structural/ Functional performance

6.1 Deflection recovery test

Deflection recovery test was carried out on the RC filler slab of clear span 3.6 m (Fig.3) considering residential floor load as per IS:456-1978[5]. The slab was subjected to full dead load and 1.25 times imposed load for a period of24 hours and the deflectionmeasured. The measured deflection was only 1 in 750 of the span. The imposed load was then removed and after 24 hours, the deflection recovery was more than 90 percent indicating that the slab passes the test.

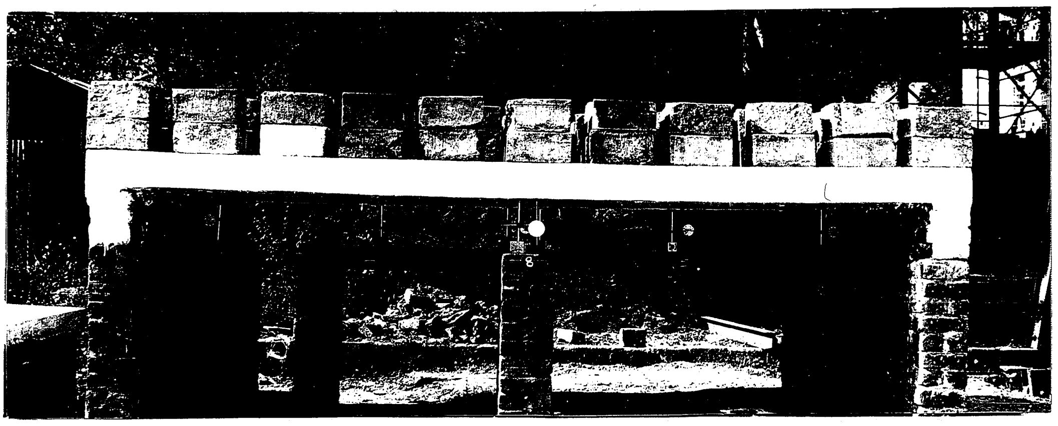

Fig. 3 Deflection recovery test

6.2 Failure load test

The slab was further subjected to failure load test. Deflections were measured and development of cracks noted at each stage of loading. The first crack was noticed at a total load of 6.7 kN/m2. The loading was stopped at a total load of 13.4 kN/m2 which is almost 1.5 times the design limit state load of 9 kN/m2. Further loading could not be done due to problems in stacking concrete blocks/sand bags over the layers already stacked. Pattern of cracks in the slab at penultimate stage of loading is shown in Fig.4.

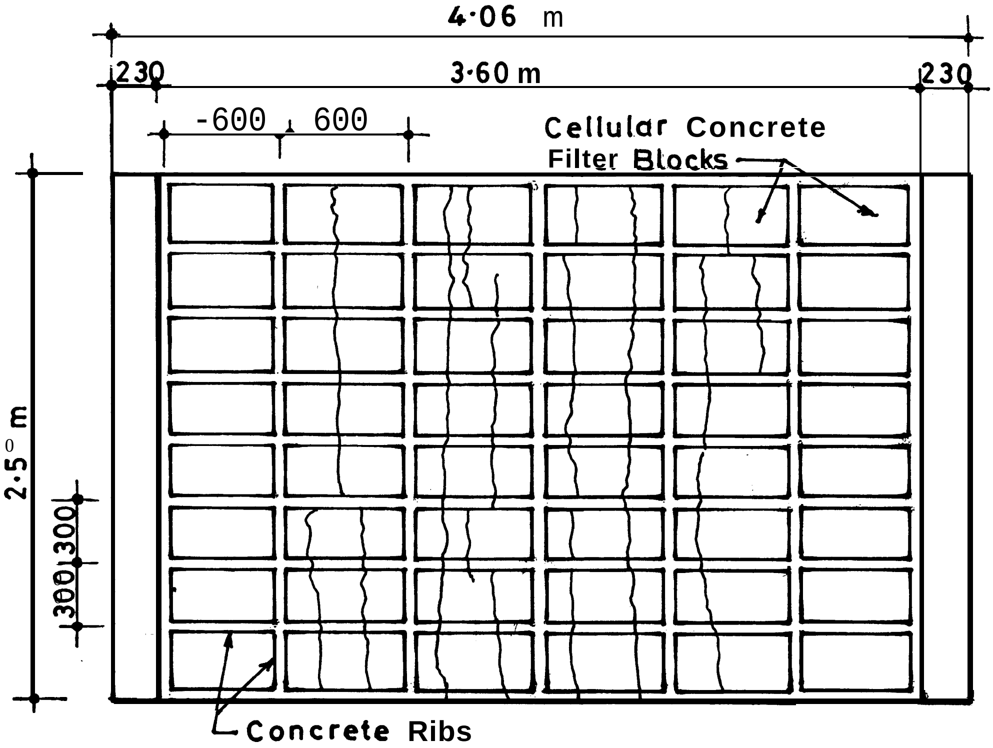

Fig. 4 Crack pattern in slab (ceiling)

As the test slab was constructed as a one way spanning member, cracks had occurred perpendicular to the span. **Major cracks had** occurred at the junction of filler blocks and cast in-situ ribs, specially in case of three ribs in the middle. Other cracks had occurred within the filler blocks and the cracks had passed through the ribs parallel to the span. The cracks were wider at bottom and tapering down towards top. No cracks were noticed in the flange portion

6.3 Impact load test

Though codes of practice **do not suggest any** procedure for testing slab against impact, some tests were carried out to check the impact resistance of the slab. A gunny bag filled with 40 kg of sand was dropped from a height of 1.5 m. No damage was observed. A 5 kg weight was dropped from a height of 1.2 m over an area of 700 mm2. Though indentation of about 2 mm was noticed at the top of the slab, where the weight struck it, no other damage was observed. The slab was also subjected to another type of impact test by pounding turmeric, one of the hardest materials used in Indian kitchens, in a "Hamam Dasta" (a heavy steel vessel), kept over the unfinished slab. No cracks or signs ofweakness had developed during or after the tests. Hence filler slab is safe against impact expected in residential and office buildings.

6.4 Thermal performance

The thermal performance [6] for the RC cellular concrete filler slab roof and the conventional RC slab roof with same roof treatment above are given below.

Specification of roof slab	**TPI**
1. 150 mm thick cellular concrete filler slab with 90 mm thick lime concrete	85
2. 100 mm thick RC slab with 90 mm thick lime concrete	134
3. 150 mm thick filler slab with 75 mm thick mud-phuska & 50 mm thick tiles	75
4. 100 mm thick RC slab with 75 mm thick mud-phuska & 50 mm thick brick tiles	110

It can be seen that with the same roof treatment, the filler slab is thermally superior to conventional RC slabs.

6.5 Sound absorption

The sound absorption properties of cellular concrete and dense concrete are 0.27 percent and 0.1 percent respectively. Thus, it can be concluded that, if the ceiling of the filler slab is kept unplastered, it is superior to conventional RC slab in sound absorption and it is suitable for class rooms, lecture halls, conference halls, auditorium etc.

6.6 Leak proofness

The slab without any treatment over it was tested for leakage by ponding water over it continuously for one week. No dampness was seen below. This indicates that if the construction is done properly, there is no chance of leakage in filler slab. However, as an ample measure of caution, it is advisable to have a waterprooftreatment above the roof slab.

7 Economy

A comparison of the consumption of materials and cost of construction of the filler slab with conventional RC slab is given in Table 1. In case A, the comparison has been made for a 3.6 m x 3.6 m two way spanning continuous slab and in case B for a one way spanning simply supported slab of span 3.6 m.

Slab	Item	Cement (kg/n?)	Steel (kg/m^2)	cost ($Rs./m^2$)
A. Two way spanning continuous slab	a) Conventional slab 120 mm thick	38.4	7.1	415
	b) Filler slab 150 mm thick	32.0	4.0	346
	c) Savings (percentage)	16	44	17
B. One way spanning simply supported slab	a) Conventional slab 120 mm thick	48.0	6.5	450
	b) Filler slab 150 mm thick	32.0	3.5	338
	c) Savings (percentage)	33	46	25

Table 1. Comparison of cost and consumption of materials

It can be seen that adoption of filler slab in place of conventional RC slab will result in a saving of about 17 percent in cost. In addition, there is a saving of 16 to 33 percent in cement and about 45 percent in steel.

8 Conclusion

This technique of construction can be easily adopted for the construction of all types of buildings, once the cellular concrete blocks are available in the market. This is possible if entrepreneurs set up production units near Thermal Power Plants, where they are given flyash free of cost and space and facilities like power and water supplied at no-profit, no-loss basis. The large scale production of the blocks will help in the problem of disposal of flyash to a great extent. In addition, it will result in saving of cement and steel and will lead to affordable housing

9 Acknowledgements

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10 References

1. IS:8112-1989, *Specification for 43 Grade Ordinary Portland Cement*, BIS, New Delhi.
2. IS:12269-1987, *Specification for 53 Grade Ordinary Portland Cement*, BIS, New Delhi.
3. IS:712-1984, *Specification for Building Limes*, BIS, New Deihi.
4. IS:3812-1981, *Specification for Flyash for use as Pozzolana*, BIS, New Delhi.
5. IS:456-1978, *Code of Practice for Plain and Reinforced Concrete*, BIS, New Delhi.
6. Building Digest *No. 94, Thermal Performance Rating and Classification of Flat Roofs in Hot Dry Climates*, 1971, CBRI, Roorkee.

Moisture migration in building walls: numerical modelling of transient water movement during a rainfall

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Abstract
A one-dimensional numerical model has been developed in order to represent rain absorption by porous building surfaces. The analysis has been performed on clay brick in two different boundary conditions: the former with a water-proof boundary condition in correspondence of the inner side of the wall, the latter with an indoor U.R. equal to 50%. A constant flux boundary condition has been applied to the external surface. The flow system is non-hysteretic and isothermal, and osmotic effects associated with soluble salts are absent.
The use of this method has permitted the evaluation of the time at which saturation occurs in correspondence at the outer surface of the wall, vs. rainfall rate.
The adopted mathematical model is based on unsaturated flow theory in porous media and on the concept of the representative elementary volume (REV). The governing equations are the mass balance equation in a porous medium and the Darcy's law. The unknown variable is the moisture content in the porous medium that is described by the difisivity parameter.
The solution is obtained by means of a finite element spatial discretization (Galerkin formulation) and the time derivative is reproduced by finite differences; the non-linearities of the problem are worked out with a modified Picard scheme. Cholesky's method is utilised for the solution of the set of system equations. The numerical code is in Fortran language. The reliability of the code has been tested comparing the numerical results with Philip's analytical solution where the difisivity is constant.
Keywords: moisture migration, numerical modelling, saturation time, diffisivity parameter, brick, rainfall

1 Introduction

The investigation of moisture migration in building materials is extremely important for the characterisation of behaviour in relation with durability, waterproofing and degradation of appearance.

At the moment, moisture is one of the primary causes for the damage observed on the envelope of buildings, increasing the importance of the development of research with the aim of defining regulations concerning the design of building walls in respect of moisture.

The scientific explanation for the many ways it may occurs has frequently been difficult due to the complexity of the problem. The use of a flexible and robust numerical model, able to simulate particular cases of interest, is fundamental to analyse and to predict the performance of building materials under any kind of external input. Finite element method is particularly suited to handling complicated geometry and boundary conditions.

2 Analysis of moisture migration

The fundamental law that describes the flow of water through an unsaturated porous material is Darcy's law which in horizontal direction may be written

$$\mathbf{q} = -K_x \frac{\partial h}{\partial x} \tag{1}$$

where: h is the hydraulic tension head [L], $\mathbf{q}$ is the volumetric Darcy velocity [L] [T^{-1}], k_x is the hydraulic conductivity of porous medium in horizontal direction, dependent on moisture content [L] [T^{-1}].

A building wall made of solid clay common brick is considered. The infiltration process is supposed isothermal and non-hysteretic; the osmotic effects due to soluble salts are negligible.

Introducing the moisture content θ as main variable, Darcy's law becomes:

$$\mathbf{q} = -K_x(h)\frac{\partial h}{\partial x} = -K_x(h)\frac{dh}{d\theta}\frac{\partial \theta}{\partial x} = -D_x(\theta)\frac{\partial \theta}{\partial x} \tag{2}$$

where

$$D_x(\theta) = K_x(h)\frac{dh}{d\theta} \tag{3}$$

is the diffusivity of the porous medium.

Assembling the Darcy's law and the mass balance expression, the governing equation of moisture migration in a porous medium takes this form:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(D_x(\theta)\frac{\partial \theta}{\partial x}\right) \tag{4}$$

The knowledge of the hydraulic diffusivity D as a function of moisture content θ defines completely the flow.

3 Numerical modelling

The finite element method has been applied to describe the water movement in a finite solution domain Ω of length L.
Linear functions are used to determine the value of moisture content in elements. As weighting functions the same linear functions are introduced (Galerkin formulation).
The hydraulic diffusivity is supposed constant in each element and equal to the arithmetic mean between the values at the corresponding nodes.
Assembling the terms related to each element (e), the following system of non-linear partial differential equations is derived:

$$[\mathbf{C}]\left\{\frac{\partial \theta}{\partial t}\right\}+[\mathbf{D}(\theta)]\{\theta\}=\{\mathbf{F}\} \tag{5}$$

where

$$C_{ij}=\int_{\Omega^{(e)}}\left(N_i N_j\right)d\Omega^{(e)} \tag{6}$$

$$D_{ij}=\int_{\Omega^{(e)}} D(\theta)\left(\frac{\partial N_i}{\partial x}\frac{\partial N_j}{\partial x}\right)d\Omega^{(e)} \tag{7}$$

and F_i is a source or sink term for nodes located at the boundary of the domain.
The system of equations (5) is then solved applying the finite difference method:

$$\left([\mathbf{C}]+\alpha\Delta t[\mathbf{D}(\theta)]\big|_{t+\Delta t}\right)\{\theta\}_{t+\Delta t}=\left([\mathbf{C}]-(1-\alpha)\Delta t[\mathbf{D}(\theta)]\big|_t\right)\{\theta\}_t+$$
$$+\Delta t\left(1-\alpha\right)\{\mathbf{F}\}_t+\alpha\,\{\mathbf{F}\}_{t+\Delta t} \tag{8}$$

where α can vary between 0 and 1. In the present study the implicit method is adopted ($\alpha = 1$) to guarantee stability in the solution and absence of numerical oscillations.
To linearized the system of equations (8) the modified Picard iterative scheme is performed. The solution is the obtained using the direct Cholesky method.
The reliability of the code developed has been tested comparing the analytical solution drawn by J. R. Philips [1] in a semi-infinite domain with $D=D^*$ = constant, independent from the moisture content. With these simplifications the equation (4) becomes:

$$\frac{\partial \theta}{\partial t}=D^*\frac{\partial^2 \theta}{\partial x^2} \tag{9}$$

subject to
$\theta(x, t=0)=0$,
$\theta(x=0,t)=\theta_1$,
$\theta(x\to\infty,t)=\theta_0$,
where θ_1 is the moisture content at saturation and θ_0 is the residual moisture content.
The analytical solution is:

$$\theta = erfc\,\frac{x}{2}\left(D^{*}t\right)^{-1/2} \qquad (10)$$

In Fig. 1 the moisture content is represented at t = 1, 2, 3 minutes from the beginning of the simulation. It's evident a complete correspondence between numerical and analytical values.

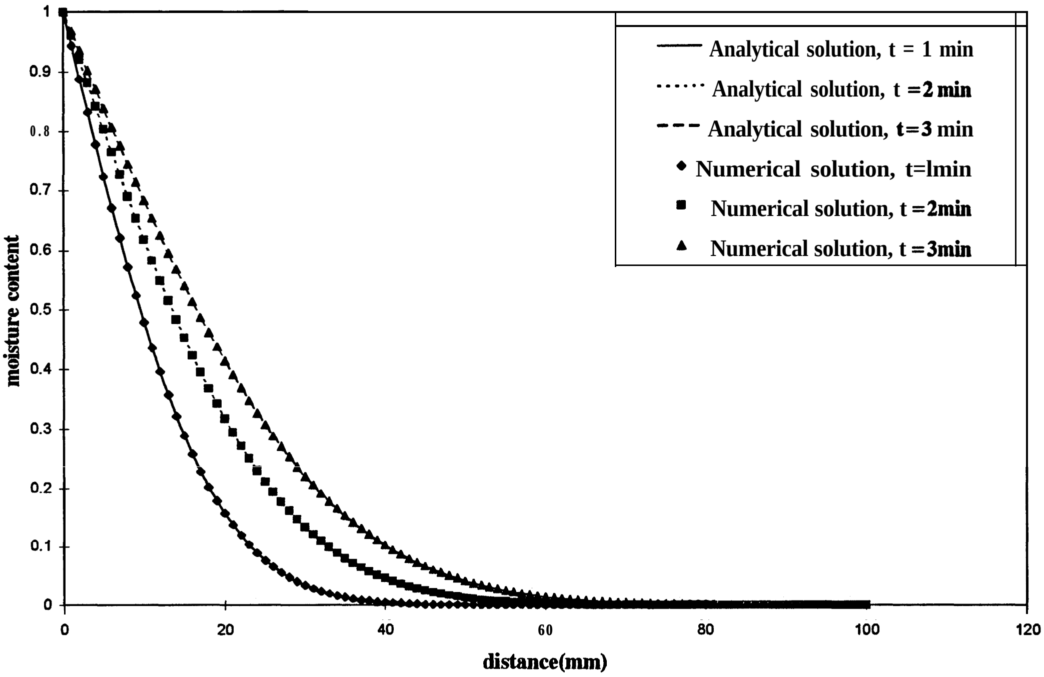

Fig. 1 Comparison between the analytical relation as proposed by Philip [1] and the numerical solution obtained for t = 1, 2, 3 minutes.

4 Analysis of absorption

The migration of water into the building fabric from a surface exposed to rainfall is simulated in two different situations: the former with a water-proof boundary condition in correspondence of the inner side of the wall, the latter with a water content at the inner side equal to the irreducible value, that reproduces a constant indoor U.R. equal to 50%, in well aerated surroundings [2].

q_0 is the rate at which rain is received per unit area of surface: it is calculated adopting the Lacy's formula [3]:

$$q_0 = 0.222\, W R^{0.88} \qquad (11)$$

where W is the wind speed and R is the rainfall rate.

A scheme of the situation analysed is presented in Fig.2.

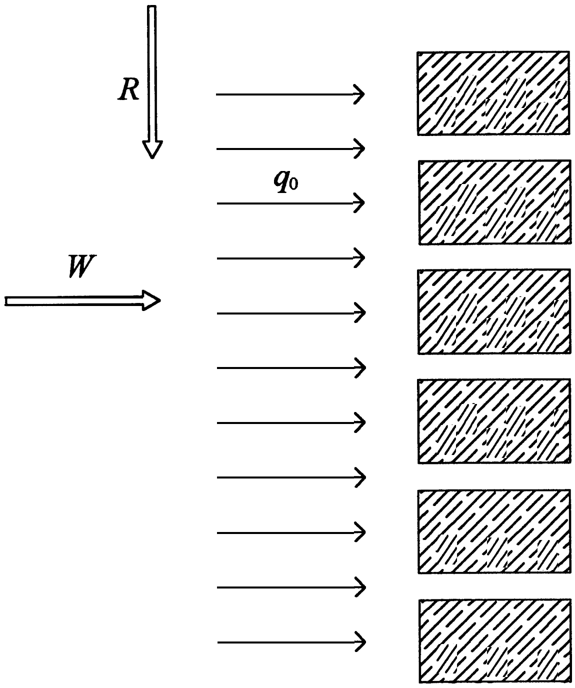

Fig. 2 Absorption mechanism of rain at the outside wall.

The hydraulic diffisivity is calculated from the expression:

$$D(\theta) = \frac{S^2}{\theta_1 - \theta_0} 0.00224 \exp(7.5\theta_r) \quad (12)$$

which has been tested experimentally for a number of building materials [4].
S is the hydraulic sorptivity of the porous medium [L] [$T^{-1/2}$] and $\theta_r = (\theta - \theta_0)/(\theta_1 - \theta_0)$ is the normalised water content

4.1 Case 1 − water-proof inner surface

Moisture migration is analysed in a clay common brick having these characteristics:
$\theta_0 = 0.002$ cm^3/cm^3,
$\theta_1 = 0.262$ cm^3/cm^3,
$S = 1$ mm/min$^{1/2}$,
$L = 12$ cm.
The initial and boundary conditions are:

$\theta(x, t = 0) = \theta_0$ for $0 \le x \le L$;

$D(\theta)\frac{\partial \theta}{\partial x}(x=0, t) = -q_0$ for $t \ge 0$;

$\left.\frac{\mathrm{d}e}{\partial x}\right|_{x=L,t} = 0$ for $t \ge 0$.

The water content profiles have been obtained for increasing values of rain received per unit area of surface: q_0 = 25, 50, 75 mm/hr. The results are represented in Fig. 3, 4 and 5.

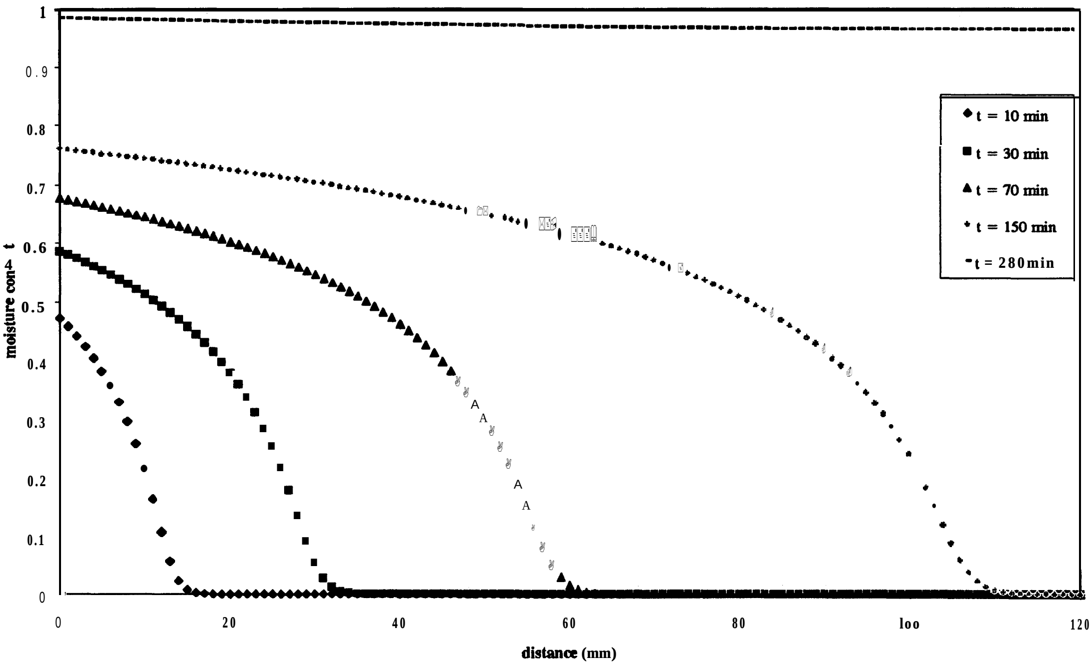

Fig. 3 Moisture content profiles (q_0 = 25 mm/hr)

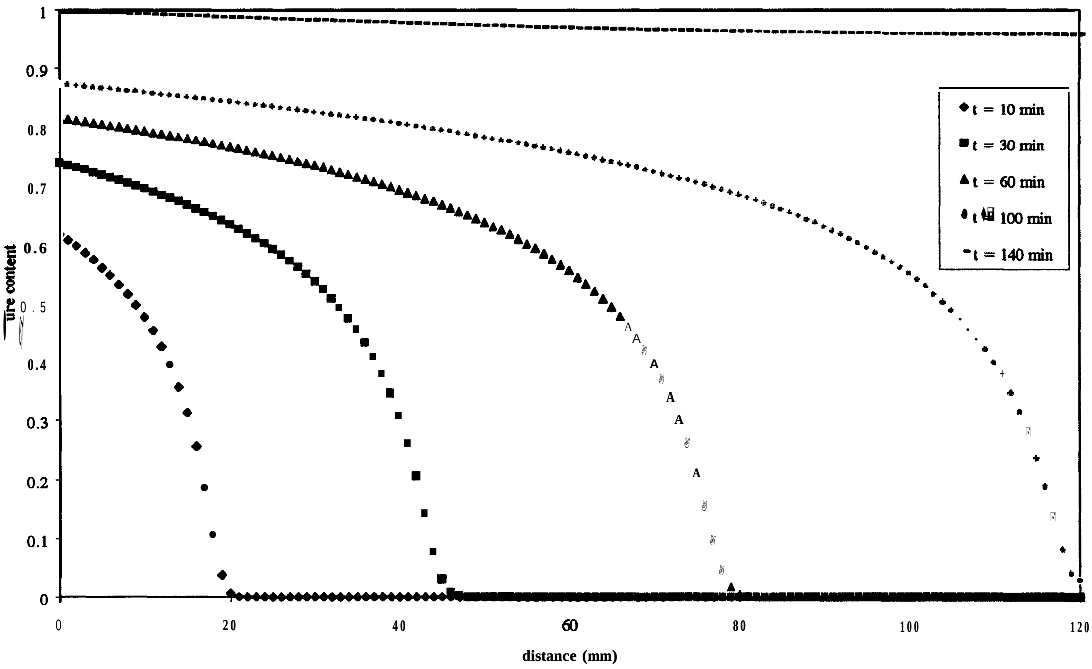

Fig. 4 Moisture content profiles (q_0 = 50 mm/hr)

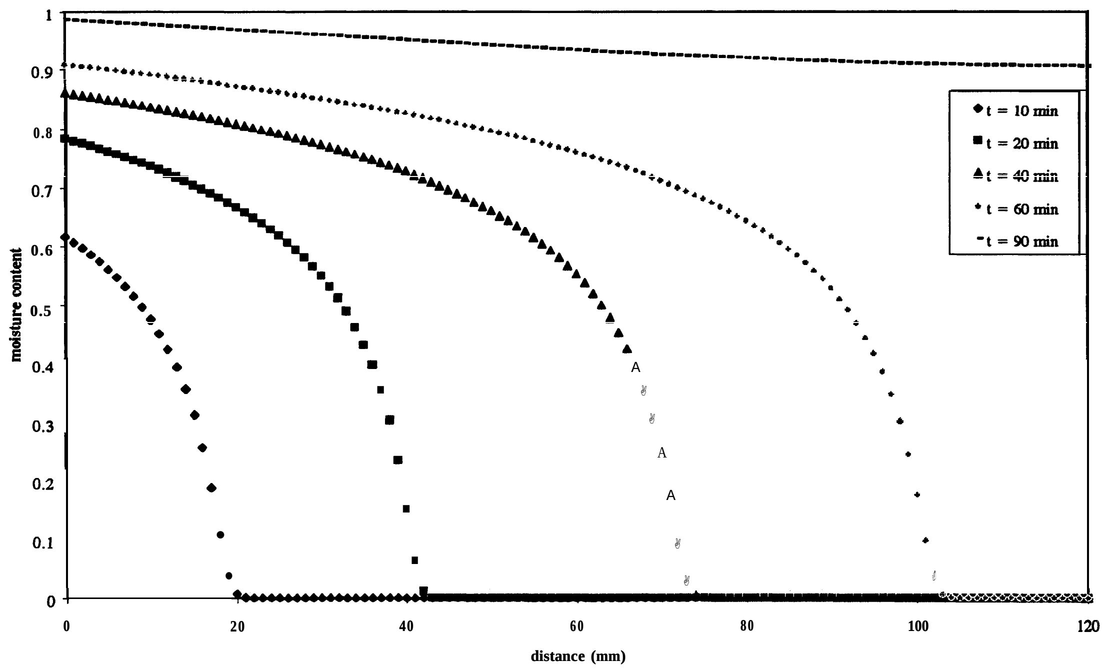

Fig. 5 Moisture content profiles (q_0 = 75 mm/hr)

4.2 Case 2 - irreducible moisture content at the inner surface

This scheme reproduces a continuous circulation of air in contact with the inner surface of the wall, so as to maintain a U.R. equal to 50%. This constant percentage of relative humidity guarantees an irreducible moisture content at the surface of the wall [2]. The characteristics of the building material are the same as in case 1.

The initial and boundary conditions are:

$\theta(x, t=0) = \theta_0$ for $0 \le x \le L$;

$D(\theta)\dfrac{\partial\theta}{\partial x}(x=0, t) = -q_0$ for $t \ge 0$;

$\theta(x = L, t) = \theta_0$ for $t \ge 0$.

The moisture migration is represented in Fig. 6, 7, 8 for q_0 = 25, 50, 75 mm/hr respectively.

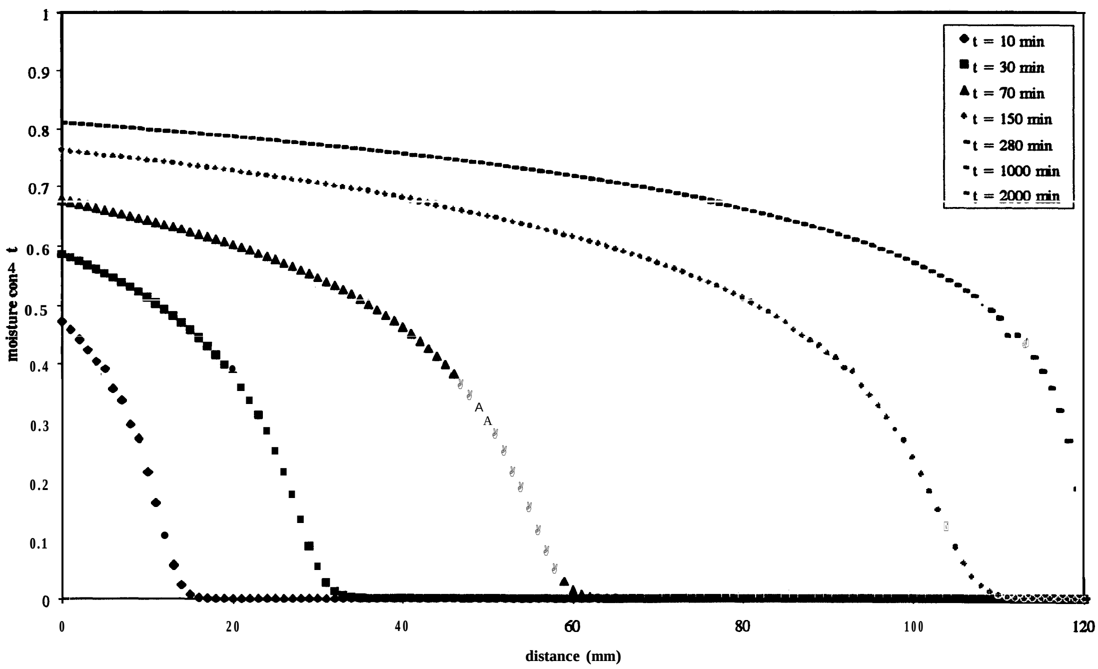

Fig. 6 Moisture content profiles (q_0 = 25 mm/hr)

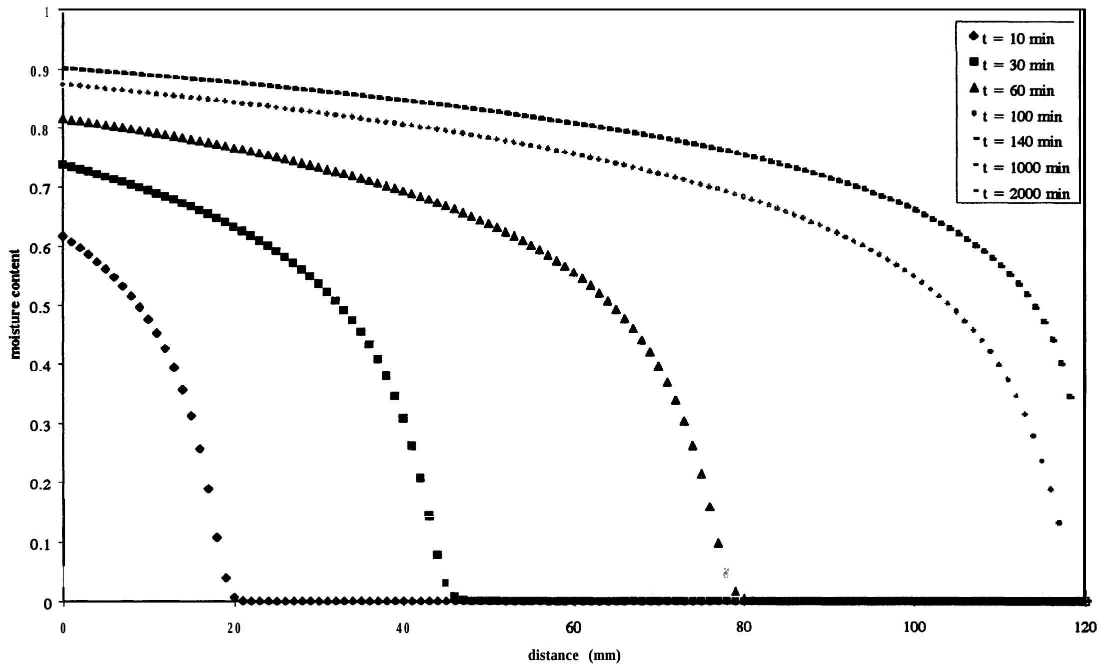

Fig. 7 Moisture content profiles (q_0 = 50 mm/hr)

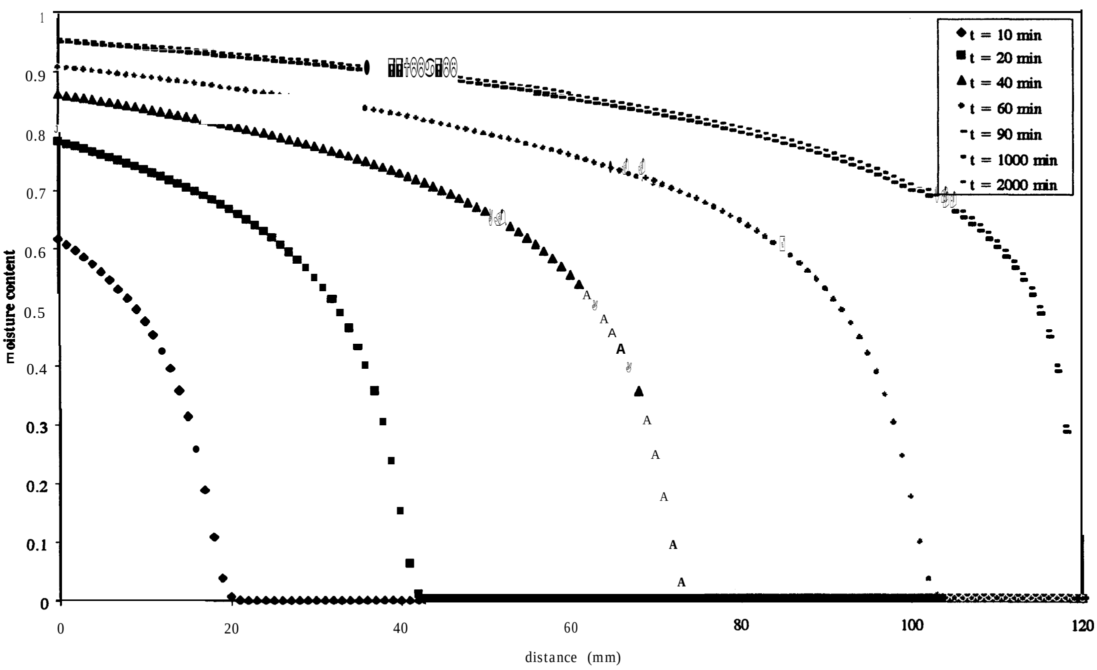

Fig. 8 Moisture content profiles (q_0 = 75 mm/hr)

5 Conclusions

The analysis of moisture migration inside a common clay brick for two different boundary conditions at the inner side of a wall has shown the different behaviour of this material for what concern saturation time of outer surface.

In case of a water-proof surface a linear relationship between incoming moisture flux and time of saturation has been observed (Fig. 9).

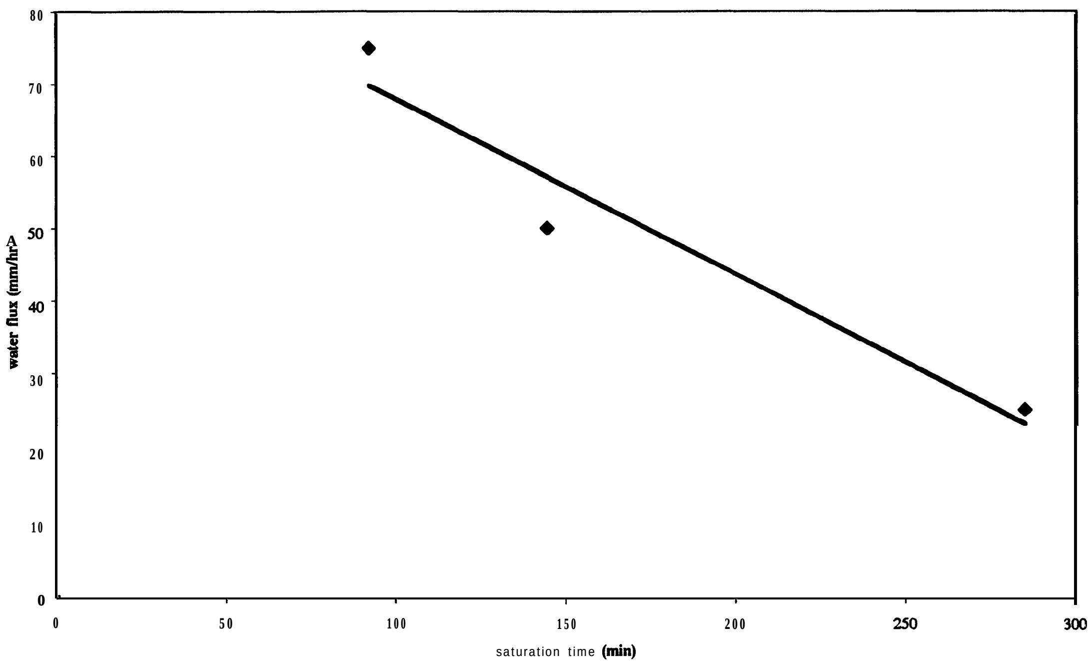

Fig.9 Saturation time of outer surface as linear function of moisture flux received in case 1 (water-proof inner surface)

For a constant indoor U.R. that ensures a constant irreducible moisture content at the inner surface the saturation of the outer side is never been achieved.
At this point it's reasonable to come to the conclusion that not only the choice of an appropriate building material could effect the durability and degradation of appearance: the conditions of surroundings inside and outside the construction should be analysed in their completeness to test the different behaviour of building fabrics. This aim, as shown, can be achieved in an appropriate way performing some numerical simulations under different solicitations.

6 References

[1] J. R. Philip, *Theory of infiltration*. Advances in Hydroscience, 5, 2 15-296, 1965
[2] C. Hall, W. D. Hoff, M. R. Nixon, *Water Movement in porous building materials - VI. Evaporation and drying in brick and block materials.* Building Environment, 19, 1, pp. 13-20, 1984
[3] R. E. Lacy, *Climate and Building in Britain.* HMSO, London, 1977
[4] A. N. Kalimeris, *Studies of water movement in building materials,* M.Sc. Thesis, University of Manchester, 198 1

Data Collection and Handling for Environmental Assessment of Building Materials by Architects and Specifiers

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Abstract
BRE has spent two years working on a UK Department of Environment, Transport and Regions funded project to develop a methodology for collecting data on building materials and components which involves twenty-five industry partners. The project is due to be completed in early 1999.

This paper describes how BRE has dealt so far with the challenges presented by collecting data from this diverse industry, including the issues arising from non-specific and over-specific information sets. The issue of industry sponsored LCA data generated using specifically devised methodology is also raised and it is suggested that such data should be scrutinised carefully to ascertain its suitability for wider applications.

Some of the rules and guidelines which will be applied in the process of handling the data to present it to architects and specifiers are described, with particular reference to the allocation for recycled material and embodied energy.

The convention chosen by BRE is that all scrap - both new and old - is considered to be “free” of resource use, energy or pollution costs, except for that which is incurred in transport to its point of use and in its transformation in the second production process. As data are collected and analysed, the robustness of this convention will be tested.

The preferred definition of embodied energy currently held by BRE is that it should be expressed in terms of the primary energy content of all the materials which are used in the process as fuels, together with the energy content of those feedstocks which are fossil hydrocarbons and are currently extracted as economic fuels.

Key **words:** Environmental Assessment; LCA, materials; specifiers

1 Introduction

In January **1996,** BRE began a three year collaborative project, Environmental Profiles of Construction Materials, Components and Buildings, funded by the UK Department of Environment, Transport and Regions. The project aim is to devise a UK methodology for the collection and presentation of data about building materials and components, to ensure that architects, specifiers and their clients can have access to reliable, up-to-date and comprehensive information. This project will result in a UK National Database of Building Materials and Components. When dealing with building materials however, it is important to realise the limitations of Life Cycle Assessment as developed by the International Standards Organisation [la] which is normally applied to single products. There is a need for an adapted life cycle assessment process suitable for comparing many different materials with varied lives and applications, coming from a variety of sources and processes.

BRE's partners in this project are twenty-five trade associations who are involved in providing the data from their member companies. A standard questionnaire has been produced by BRE and a brisk timetable for collection drawn up. The response to the call for data by different organisations has been very varied and has raised a number of issues. In addition to the problems during data collection, there is the challenge of deciding the most equitable way to treat the data once it has been obtained. This paper discusses the ways in which BRE and its project partners have tackled the data collection process and some of the developments in our methodology.

Any data collection activity must recognise the commercial realities of industry and the considerable investment of time and commitment involved. Industries are understandably cautious about providing life cycle inventory data for a number of reasons. Their main concern is the unknown impact of the analysis on their commercial position resulting from:

- Uncertainty about their relative performance
- Fear of poor performance because they use inputs from less efficient industries.

This is something which must be addressed by increasing industry involvement, for example through personal letters, news sheets and by meeting with those who are to be involved directly, in order to allay their fears. However, it should be recognised that many materials producers still consider publicising environmental performance to be a new and uncomfortable idea, so the dialogue achieved through data collection is a valuable contribution to the promotion of environmental improvements in the UK construction materials industry.

2 The LCI data collection process

The different histories, structures and concerns of the trade associations working with BRE have led to them providing data to the Profiles project in a number of different ways. Some of these are outlined below. These differences require us to make judgements and decisions about the best way forward to meet the aims of the project and our experience so far is summarised and discussed in this section.

2.1 Provision of generic data

Over the course of the project, the trade association for a particular product has been willing to provide data but the industry was concerned about its potential use. Their response to this has been to convene a special working party to consider how the range of products they create for construction should be represented in the project.

The working party decided to provide data about their industry's "typical product", using unattributable data and products. They came to this decision for two reasons. Firstly, because the industry infrastructure is very varied and consists of modern plants, as well as plants which are far less efficient but produce much sought-after products. Secondly, because the process is geographically diverse, due to the nature of the raw materials they use, they felt that the variation between products across the country could provide misleading results.

Their working party has begun by making an independent choice of the typical process and typical product for which they will provide data. BRE has requested that they make the process they are undertaking as transparent as possible and is seeking to ensure that the project receives data that can be accepted with confidence but which the industry does not feel is an infringement of their confidentiality.

Where data collection processes are not transparent, it is not possible for researchers to verify data received for a project. In such circumstances, the only recourse is to take this "typical" data and then apply knowledge from existing data to assign relative values to their different products. This is not satisfactory, but does provide a route for updating existing data and thus improving upon the *status quo.*

2.2 Provision of 'representative' industry data

An example from the opposite end of the spectrum has been the response of another industry which has provided data on the manufacture of products from just two plants, belonging to the same company. Two plants represents quite an achievement for the trade association, who at first doubted the possibility of collecting new data at all. They have chosen two highly representative factories and now believe that their data would not be improved by collecting more widely. This data is of a good quality due to its highly transparent nature, the ease with which it may be checked and the age of the data. The extent to which it is representative for the UK will be checked against published sources as well as by peer review by other industry sectors.

Some data on overseas production of materials is also highly selective, owing to the scarcity of data on the subject, and there is a danger that the efficiency in the country of origin is significantly more or less than average. The most reasonable solution is to ask industry experts how much they consider these figures to differ from the norm.

This is similar to the situation for most metal ore extraction which also takes place overseas. Studies available are ***ad-hoc*** and incomplete but are all that researchers have to rely upon. The primary and secondary processing industries in developed countries usually exercise no control over the processes and hence data from distant mines, and so their studies of their materials typically focus on processes within their own factories. Like other LCA researchers, BRE will use available figures with appropriate indications of quality.

2.3 Inclusion of industry sponsored LCA results

The members of the construction materials industry differ greatly, in terms of resources and history, in their ability to provide environmental information. Some industry sectors are much further advanced in their appreciation of LCA than others and are aware of potential advantages that LCA can bring to their sector. This is good news for the acceptance and development of the methods behind LCA. Some partners in the BRE project are representatives of industries engaged in large international LCA studies and the results of these will be their contribution to the project. The results are end figures and could potentially provide a welcome short cut for smaller national studies.

These international studies each have their own methodology, which is a potential problem for the present project, designed to create a common methodology for the construction materials industry. It is highly desirable that we use data for comparative studies which have been derived using the same allocation rules, boundary settings and conversion factors for at least the most significant aspects of the life cycle, i.e. those that make the biggest contribution to the impact of a product. Ideally the project team will have access to the raw data from these international studies in order to apply their own rules and thus convert them to comparable values.

Where industry specific rules have been applied, the value of the resulting data are difficult to interpret when those rules do not conform to those of a project. However, if there is no alternative then such data can be used, but the source of the data and its differences must also be made clear in the associated literature.

2.4 Excluding poor performers

Some industries are very small and there are very few manufacturers of a product. This provides a special challenge to LCA studies, where the confidentiality of the contributors cannot be protected by generating average figures in the usual manner. An example has arisen where two-thirds of a small industry belong to the trade association. These manufacturers are happy to contribute data which will be provided to us as one figure that they have agreed on - they prefer to make a common stand rather than compete with each other. The other third of the industry, however, uses a far less efficient process than the others and its inclusion would adversely affect the data from the other two-thirds. Consequently, the trade association have not sent the questionnaire further than their members. This does not help the purchaser of this product, however, whose goods “off the shelf’ could come from any manufacturer.

Researchers have a difficult task to provide meaningful data for architects without penalising good performers. This problem clearly highlights the need to have the next stage of environmental profiling available for manufacturers to exploit; i.e. individual product declaration, something which BRE is working on.

2.5 Data collection in context

From the experience of other data collection exercises, it has clearly been a considerable achievement to get so many industry representatives meeting together and providing data for a common purpose. The data, in all its varied forms, will make an extremely valuable contribution to existing information sets. However, no-one should underestimate the difficulties of using these data as inputs to LCA. This project, and others like it, are still having to discover new ways to cope with the uncertainty and variability present in data provided within the limits of commercial realities. As our knowledge increases, many of these obstacles should disappear as we become able to focus with increasing precision upon those areas which will allow designers and clients to make a difference to the environmental impact of the construction and refurbishments of buildings

3 Rules and guidelines

To analyse and present the inventory data obtained through data collection it is necessary to establish rules and guidelines. The following paragraphs explain how BRE has developed aspects of these procedures to accommodate the needs of material producers whilst maintaining an equitable system for all products.

3.1 Allocation to co-products

The IS0 DIS 1997 [la] recommends that inputs or outputs of a system should be partitioned between its different products in a way which reflects the underlying physical relationships between them. However, if this is not possible, allocation between co-products can be in proportion to their economic value. It is unlikely that a single allocation procedure can be used for all co-products in an LCA. Most require a mix, each one clearly justified, possibly with the inclusion of sensitivity analysis to aid choice between options. For this project, the preferred option is to use physical relationships but, where the level of detailed data collection is inadequate to do this, allocation will be in proportion to the three year average selling price at the factory gate of each co-product.

3.2 Recycling

Recycling is an important issue for building materials. It must be clear when materials move within a process as scrap and when they move from one to another as by-products or waste. There are three categories of recycled material which must be considered:

1. Produced and recycled within an industrial process
   So-called "home scrap" is a material flow which is internalised within the inputs and outputs of the process boundary and so is ignored in the inventory. However, it results in an improved conversion efficiency and reduced waste output.
2. Material from one industry which becomes the raw material for another
   This is sometimes called "new scrap" because it generally arises soon after the initial material was produced. An example is the material produced after the pressing of car bodies from sheet steel.
3. Post-consumer waste that is recycled and becomes a raw material. This "old scrap" is that which arises at the end of a product life.

The convention chosen by BRE is that all scrap - both new and old - is considered to be "free" of resource use, energy or pollution costs, except for that which is incurred in transport to its point of use and in its transformation in the second production process. However, even scrap materials which are traded and have a value will have zero burdens and this is an exception to the convention described above, that by-products could be allocated interventions in relation to their price. As data are collected and analysed, the robustness of this convention will be tested and reference will be made to the detailed examples given the IS0 DIS [lb].

When a material has been processed from both virgin and recycled sources, its environmental interventions will be calculated using the current average proportions of the two for the use of that material in construction and the interventions will be only those of the virgin material.

3.3 Imports

The inputs and outputs attributed to imports of raw materials, feedstocks and products will, wherever possible, be based upon analyses appropriate to the country of origin and will include the energy of transportation. Where data for the country of origin are not available, the input and output data will be based upon the closest domestically produced product with an addition made for the transportation from the country of origin. The exception to this is for imported refined fuels and electricity; these are attributed the same environmental interventions as those generated from primary sources for use within the UK.

4 Classification of inputs and outputs

The preparation of the inventory in LCA produces a long list of values for a wide variety of substances - raw materials, fuels used, emissions to air, water and land. The next stage in LCA is categorisation in preparation for impact assessment. It is not intended to carry out impact assessment in this project; the aim is to produce an environmental profile of the results of the inventory. However, it is possible that some of the data will be grouped into categories to enable single values to be assigned to particular effects. Embodied energy can be considered to be an input category of the life cycle of a material, while embodied carbon dioxide is an output category.

4.1 Embodied energy and embodied carbon dioxide

There is no definition for embodied energy in the IS0 Standard or DIS. The generally accepted definition is that produced by International Federation of Institutes of Advanced Studies (IFIAS) at a summer school on energy analysis in 1974: "the total primary energy that has to be sequestered from a stock within the earth in order to produce a product or service" [2].

The energy used in the extraction and processing of a material or product used in construction is sometimes defined *as* its *initial* embodied energy. This distinguishes it from the energy used at other stages in the material life cycle, for example in repair and maintenance.

Although values for initial embodied energy may be calculated on a mass basis as part of the unit process data, they must only be used to make comparisons between viable alternative functional units i.e. components, elements or whole buildings with the same function. Once an element or building has been defined (either a “real” design or an archetype) then the whole life of the materials and products can be included in the embodied energy value - the energy used to extract, transport and process raw materials, to convert them into manufactured products and components, to transport them to the construction site and incorporate them into a building. Just as with any other environmental effect over the life of a building, the values should also include the embodied energy of the materials used in the repair, maintenance and refurbishment of the element or building, as well as the energy to dismantle them and dispose of the materials from which they are composed [3].

The definition used for this project for the embodied energy of a material over the life of a building is:

The total primary energy that has to be sequestered from a stock within the earth in order to produce, transport, maintain and dispose of the materials within a specified product, component, element or building.

Embodied carbon dioxide will be estimated as a separate value because, although a major proportion is the result of the use of fuels of all kinds, some processes in building materials production release CO_2, for example when carbonaceous materials are heated and when carbon anodes are oxidised in aluminium reduction.

4.2 Calculation of values

The definition of “stock within the earth” requires interpretation in order to determine which input data should be aggregated to calculate a single value for embodied energy.

The interpretation adopted by IFIAS when concerns were first raised about the use of fossil fuels, required that only non-renewable hydrocarbons (and then confined to those which are extracted as economic fuels) are included in the estimate. Fuel and energy use is converted from delivered to primary terms and then only the energy obtained from fossil fuels, and not that produced from renewable sources, is included in the aggregated estimate.

This approach is used by others working in the area, particularly those with a background in energy analysis. A study from New Zealand defines energy as that “from fossil fuel sources (coal, gas, oil or other petroleum products), electricity or geothermal steam” [4]. However, there are other studies [5] in which embodied energy data are the sum of all the delivered (process) energy consumption during the manufacturing process.

There is the opinion amongst the industry representatives who are partners with BRE in this project, that all energy is valuable and contributions from all sources ought to be included in the embodied energy value. By adopting this view, embodied energy is effectively “energy consumption”; an aggregation of all fuels and energy including that from wind and hydro-electricity and timber residues. The two values for embodied energy and embodied CO_2 together provide a way of distinguishing between processes which rely on fossil fuels and electricity, which will have comparatively high embodied CO_2 values, and those which use renewable energy sources, such as timber-based residues for which embodied CO_2 will be lower.

For embodied energy calculations, primary energy will be evaluated as the sum of:

a) the gross calorific value of the fossil fuels extracted from reservoirs within the UK or imported in crude form into the UK
b) the thermal equivalent energy generated in nuclear power stations calculated as the electricity generated divided by the average thermal efficiency of nuclear stations
c) refined fuels and electricity imported into the UK, counted as having the same embodied energy per unit of fuel as those generated from primary stocks for use within the UK.

The term "embodied energy" is effectively an accounting analysis and in no way refers to the physical or chemical composition of the materials, and is not meant to imply that there is an inherent energy content that can be recovered by combustion. Consequently, the only energy of feedstocks included in this calculation is that obtained from fossil hydrocarbons which are extracted as economic fuels e.g. oils. This view is shared by the authors of the guidelines for the Athena project [6a, b]. The impacts of the use of other organic materials as feedstock and renewable energy sources are addressed within the inventory and further phases of LCA.

The preferred definition of embodied energy currently held by BRE is that it should be expressed in terms of the primary energy content of all the materials which are used in the process as fuels, together with the energy content of those feedstocks which are fossil hydrocarbons and are currently extracted as economic fuels.

5 References

1a. ISO, ***1997. Environmental*** *Management* ***- Life cycle assessment - Principles and framework.*** BS EN IS0 14040 : 1997.
1b. ***Environmental management - Life cycle assessment - Goal and Scope Definition and Inventory Analysis*** Draft International Standard ISO/DIS 14041. June 1997.
2. Chapman P F and Roberts F, 1983. *Metal* ***resources and energy.*** Butterworths.
3. Howard ***N*** P, ***1996. Embodied energy and consequential*** *CO_2* ***in construction.*** In: Proceedings of International Symposium of CIB W67 "Energy and Mass Flow in the Life Cycle of Buildings". Vienna, Austria, August.
4. Alcorn A, 1995. ***Embodied energy*** *coefficients* ***for building materials.*** Centre for Building Performance Research, Victoria University of Wellington, New Zealand.
5. Lawson B,1996. ***Building Materials Energy and the Environment. Towards ecologically sustainable construction.*** Royal Australian Institute of Architects.
6a. Athena, ***1993 Building materials in the context of sustainable development: research guidelines.*** Appendix in Phase III Summary Report. Forintek Canada Corporation and Wayne B Trusty Associates Ltd.
6b. Athena, 1997 ***Research Guidelines.*** January 1997 revision. Athena Sustainable Materials Institute.

Experiences from life-cycle assessments on steel and concrete composite bridges

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Abstract
The Swedish Institute of Steel Construction has made LCA's on steel and concrete composite road bridges in order to detect important environmental impact parameters and to find areas where improvements are necessary. The experiences may be a foundation for future environmental studies on bridges. In this project two of the most common Swedish steel bridge types were studied, one box girder bridge in 8 spans and one I-girder bridge in a single span. Both bridges are spanning over water. All main materials in the sub and super structures were included in the analysis. Details as bearings, joints and drainage system were excluded.

Combustion engines in vehicles contribute to a big share of the airborne emissions, such as CO and NOx. Though, the cement and steel manufacturing processes emit most of the CO2. The concrete in steel bridges contributes to between 40 and 50% out of the environmental impact, and the fact that steel bridges need less material than concrete bridges shows that steel bridges are good environmental choices. Three different impact assessment methods have been used to get multi-comparable and objective assessment results, the EPS Method, the Environmental Theme Method and the Ecoscarcity Method. There are very big differences in the results from the methods. In spite of the small amounts, alloys as Molybdenum contributes to most of the environmental burden from the materials according to the EPS method. This put steel in a less favourable position when comparing LCA results with other materials. This fact also affect the total EPS results, showing that the bridge is polluting more than the traffic (5000 vehicles a day) over 50 years. One joint result from the two others is that the use of the bridge (traffic) is the most polluting part during the life cycle, depending of NOx, emissions and big use of energy. The complete study with results and experiences is presented in [8].
Keywords: bridge, concrete, construction, environment, EPS, LCA, steel, zinc

1 Background

Life Cycle Assessment according to an established method is one way to reach satisfactory and comparable results regarding environmental impact from emissions, raw material use and energy consumption, independent of material or construction. The results can be used for environmental product declarations, process and product improvement analysis, as a tool in the IS0 14000 work and other environmental work where the industry has to be competitive and fulfil external demands.

The construction and material manufacturing industries are recognised as polluting industries, and are therefore put under special observation, not only in Sweden. The nature and ourselves need low-pollutant building component manufacturing and usage, in order to maintain health and welfare. Therefore, it is very important to collect objective environmental information and environmental impact life-cycle data about steel, and distribute it to those who can influence the choice of constructions and materials, and by that the environmental situation of tomorrow.

2 Analysis

2.1 Objects

This example includes a study made for a steel box girder bridge with concrete decking in 8 spans, and a steel I-girder bridge with concrete decking in a single span. Data from Sweden, Norway and Finland were used.

Bridge 1 is 492 metres long (longest span 65 metres) and 13.0 meters wide. The height of the superstructure varies between 2.0 and 3.3 metres. The single girder is painted with zinc epoxy and polyurethane, and the railings are specially designed tubular profiles with zinc coating. The bridge is situated in the Höga Kusten area about 600 kilometres north from Stockholm, spanning over a lake. Schematic sections are shown in figure 1.

Bridge 2 is 60 metres long (span 49 metres), 7.5 metres wide and superstructure height of 2.5 metres. The two I-girders (h=1.9 m) are painted as bridge 1, but with standard hot-zinced U-profiled railing beams. The bridge is spanning over a river, situated about 550 kilometres north from Stockholm.

For the comparing calculations, the data for the connecting road have been used with normal conditions. No extra ground improvement or piling is included. The traffic intensity used in the calculations is 5000 passing vehicles a day for bridge 1, and 500 vehicles for bridge 2. This corresponds to the site conditions. The length of the compared road and the driven distance for the vehicles is the same as the length of the bridge.

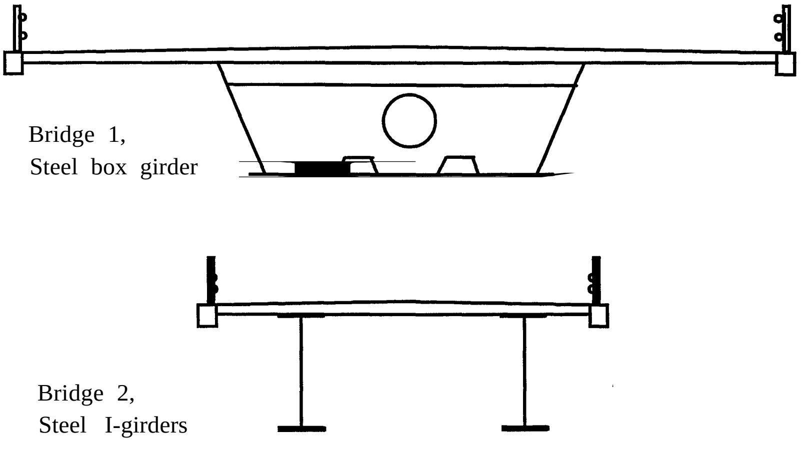

Figure 1: Schematic sections for the two studied bridges.

2.2 System boundaries

All processes from cradle to grave are included, i.e. raw material extraction of primary materials and additives, refinement processes, product manufacturing, construction and transports, and also an assumption of the utilisation, maintenance and demolition phases. Production of mills, machines and vehicles, refining of oil products and production of electricity is not included in this analysis. The normal electricity in Sweden is produced from water and nuclear power plants. The wintertime top use of fossil fuels is not included.

Studied bridge components are the substructure including piling and the superstructure including railings and deck surface. Small details, joints and bearings are excluded. Studied materials and products are constructional steel and steel piles, reinforcement steel, hot zinced steel railings, concrete for substructure, concrete for superstructure, deck insulation, asphalt surface, zinc and steel protective coating (zinc-epoxy and polyurethane paint). The data is used and adapted to Swedish conditions. The bridge utilisation used in the calculations is 50 years.

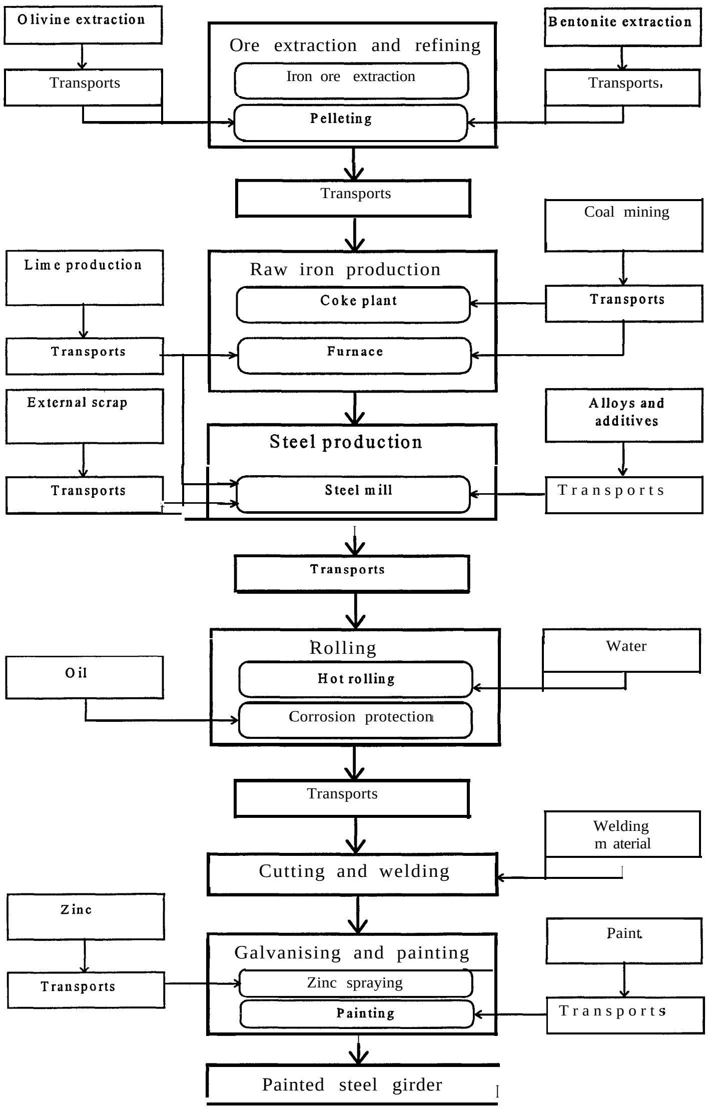

Figure 2: Example on material input for a steel girder

2.3 Inventory

The inventory includes all state-of-the-art data available on the products and processes within the system boundaries. Data is collected from manufacturers in Sweden, Norway and Finland. The studied unit is environmental impact (as kg air emission) per square meter lane. The product inventory follows a specified scheme that is individual for each product. Material input for the steel girders is shown in Figure 2. An LCA study include energy input and also material and energy output for all processes. The material output is described as primary product, by-products, waste and emissions to air and water.

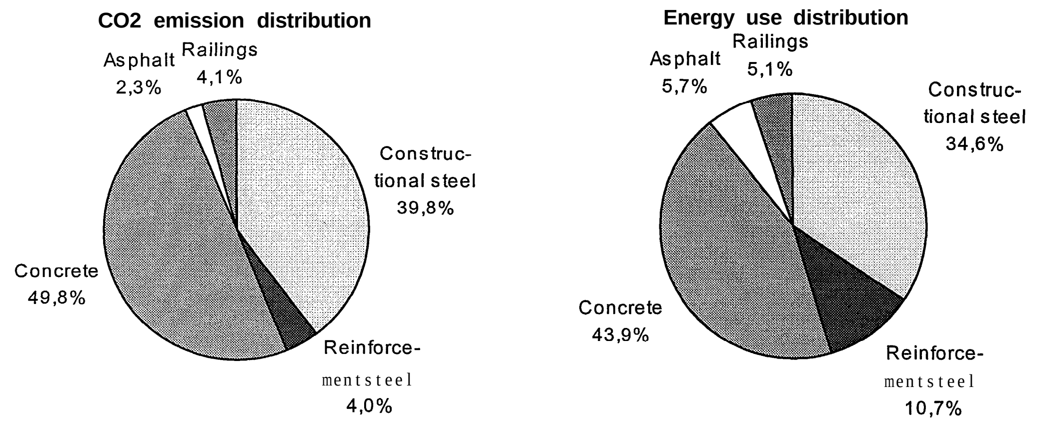

Figure 3: Two examples on inventory result distribution for the box girder bridge

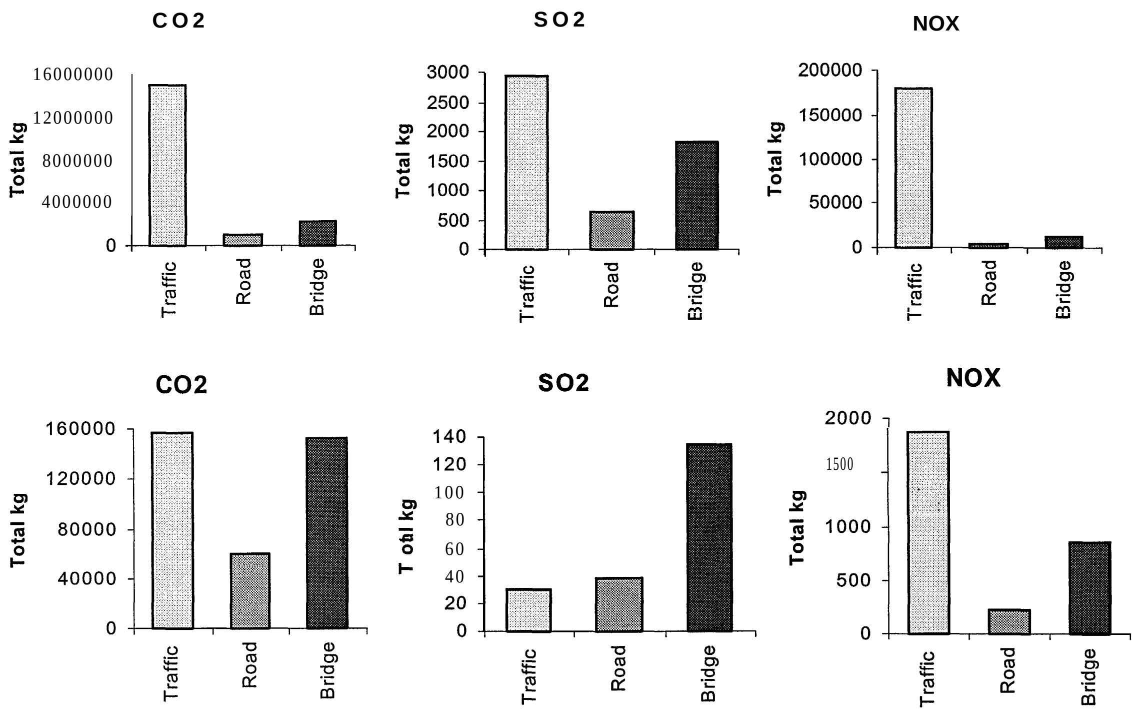

Figure 4: Inventory result comparison examples for bridge 1 (top) and bridge 2

The allocation principles used for the multi-recyclable materials steel and aluminium are according to [1]. The other product allocations have been executed with the cut-off method according to [5].

The inventory results can be analysed in many ways. Figure 3 shows the distribution for the global warming emission CO2 and the total energy requirement for the different studied parts in the bridge. These data are valid for the box girder bridge. One result is that the shares from coating are below 0,2%, and are therefore not presented in these figures. The coating manufacturing data are not complete according to secrecy.

Vehicles carrying the materials and products contribute to an important part of the CO and NOx emissions. The main sources of the CO2 emissions are manufacturing of cement and steel. The comparisons of important emissions and energy between bridge, road and traffic are shown in Figure 4. The original road LCI data come from [7].

3 Assessments

3.1 Environmental impact

The environmental impact assessments have been made with three different European methods: EPS (Environmental Priority Strategies in Product Design), the Environmental Theme Method and the Ecoscarcity Method.

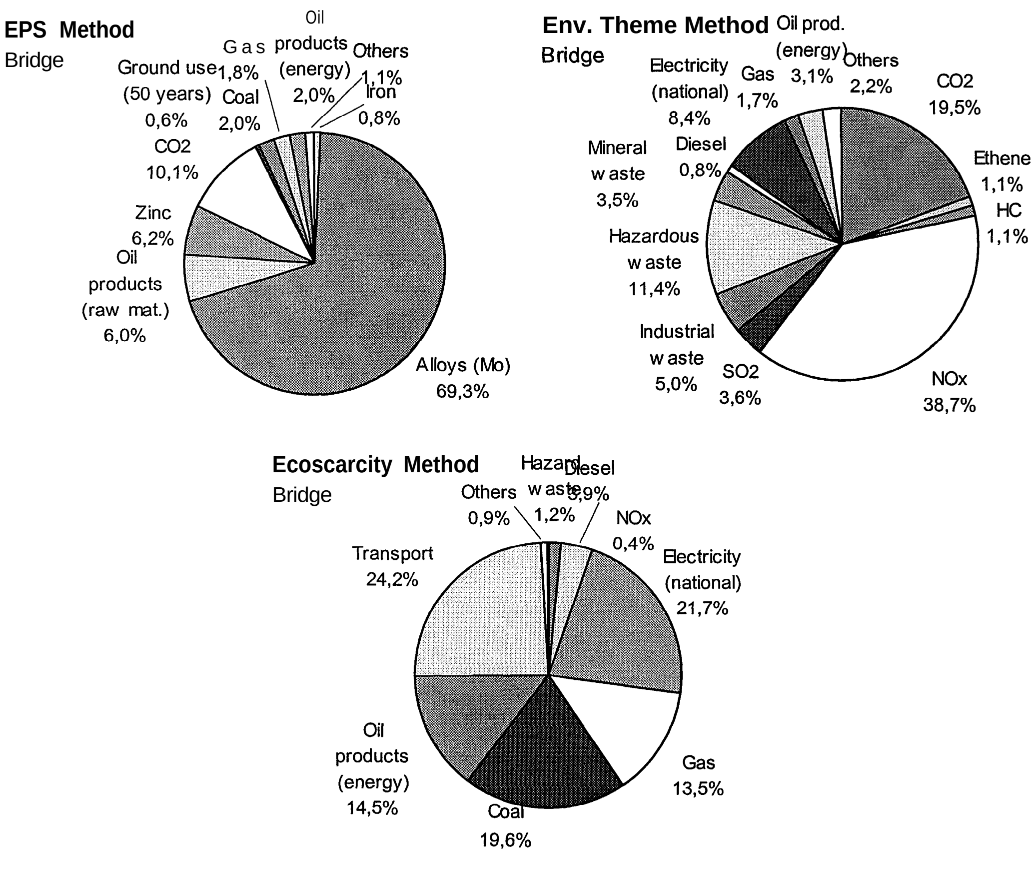

Figure 5: Assessment results from three methods for the box girder bridge

The original thought with the EPS method was also to assess the total environmental burden cost from emissions, energy use and raw material extraction, based on willingness to pay to avoid the different burdens. These assessment methods are adapted to Swedish conditions concerning political goals, material availability or ecological hazardousness.

The EPS Method is based on the willingness in the OECD countries to pay in order to avoid specific environmental impacts. The Environmental Theme Method is based on categorising of environmental burdens in effect categories, compared to the total environmental burden. The Ecoscarcity Method is based on the relationship between the current impact and the maximum acceptable (critical) impact within a specific geographical area.

The impact results from these methods for bridge 1 are shown in Figure 5. The combustion of fossil fuels affects the results obviously. This include mainly heating and transports. As shown, the CO_2 and NO_x impacts are the dominating emissions. The presence of alloys in the figures, more than 90 percent is Molybdenum, is a result of the rare raw material (ore). Zinc is also regarded as an environmental burden because of the same reason. The Ecoscarcity Method is punishing all use of energy very hard. The results from the two bridges are rather similar, except for the traffic. The percentage of concrete is higher in bridge 2, therefore giving more CO_2 emissions and less impact from alloys and other metals.

In Figure 6 comparisons have been made between bridge, road and traffic for the two studied bridges. This has been made to put the bridge in its intended function. The differences are highly depending on the traffic amount passing the bridge. The difference between the traffic on the two bridges is obvious (5000 and 500 vehicles per day).

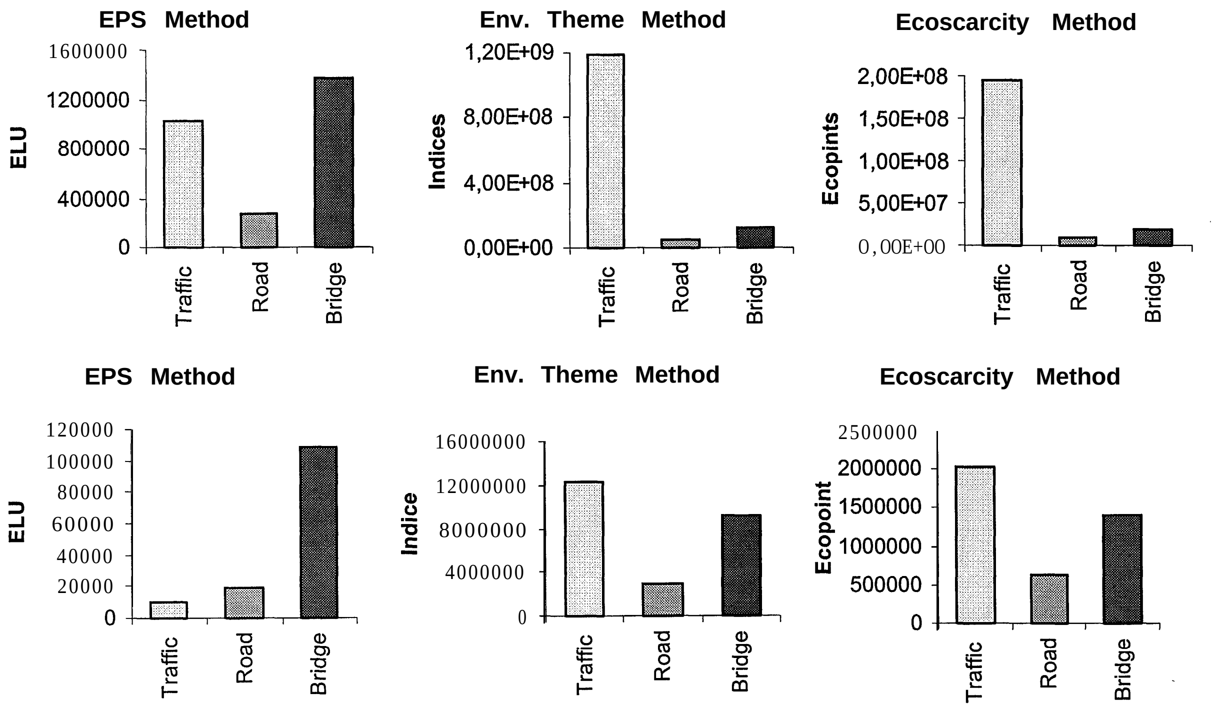

Figure 6: Assessment result comparison examples for bridge 1 (top) and 2

3.2 Environmental cost

The approximate method for evaluating the environmental burden cost give too approximate results to be used practically. These results show that the environmental cost for bridge 1 exceed the construction cost five times. This is the cost that the people in the OECD countries are willing to pay to avoid certain environmental effects. A method for evaluating the real total cost for building a bridge could be useful for this purpose. Some methods are under development in Sweden. The current cost assessment methods are too approximate to give reliable results. These will therefore not be shown in this presentation.

4 Improvement analysis

The emissions CO2, NOx, SO2 and CO correspond to more than 95 percent in weight out of the total airborne emissions. A reduction of these emissions will therefore improve the total environment impact from building and using the bridge. These can e.g. be reduced by changing the transport systems from road to railway traffic, use of bio-fuels for the vehicles, process development or changes of the cement production, and also by using coal and coke more efficient when producing steel.

Further optimisation of the material amounts used for construction of the bridge also reduces the total environmental burden. As environmental effects from the maintenance part is very small, there is not important to increase the longevity by using a lot of corrosion protective substances or extra amounts of material to prevent material deterioration. Examples of such reducible protecting materials are concrete, paint and zinc.

In spite of the small amounts, alloys as Molybdenum get high environmental impact values compared to other materials, all because of the rare raw material. It is not possible to avoid micro alloys in the steel material, but this shows the environmental advantages of choosing micro alloyed steel before steel with higher percentage of alloys. The use of high strength steels (more than 420 MPa) would reduce the total material amounts, but they usually include higher percentage of alloys as Molybdenum. Though, steel can be regarded as a good environmental choice for bridges.

5 References

1. Anderson J., Borg M., (1997). *Development of a Quantitative Methodology for Assessing the Environmental Impact of Recyclable and Reusable Products,* Report 187:4, The Swedish Institute of Steel Construction, Stockholm, Sweden.
2. Björklund T. *et al.,* (1996), *LCA of Building Frame Structures,* Report 1996:8, Chalmers University of Technology, Gothenburg, Sweden.
3. Borg M., *(1997). Livscykelinventering av kallvalsad varmförzinkad stålplåt,* Report 197:9, The Swedish Institute of Steel Construction, Stockholm, Sweden.
4. Fraanje P. *et.al.*, (1993), *Milieubelasting van twee aanbruggen, Een pilot study,* Report 57, Milieukunde, Amsterdam University, Amsterdam, The Netherlands.

5. Lindfors L.G. *et al.*, (1995), *Nordic Guidelines on Life-Cycle Assessment,* Nord 1995:20, Nordic Council of Ministers, Copenhagen, Denmark.
6. Ryding *S.O. et al.*, (1995), *Miljöanpassad produktutveckling,* The Swedish Industry Association, Stockholm, Sweden.
7. Stripple H., (1995). *Livscykelanalys av väg. En modellstudie för inventering,* Report B 1210, The Swedish Institute for Water and Air Research, Gothenburg, Sweden.
8. Widman J. (1998). *Livscykelanalys av Stålbroar,* Report 183: 1, The Swedish Institute of Steel Construction, Stockholm, Sweden.
9. Widman J., Anderson J., (1997), *Miljö. Fakta om LCA*, Report 182:3, The Swedish Institute of Steel Construction, Stockholm, Sweden.

Quantitative evaluation of the effect of pollutants on the atmospheric corrosion of structural metals

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Abstract
Evaluation of the effect of atmospheric environment including acidifying pollutants on weathering steel, zinc and aluminium is based on 8 years results of testing in open air and in rain-sheltered position within the ICP UN ECE on effects on materials. An extensive statistic analysis of results (environment, corrosion losses) was performed.

A five-factor model was proposed as derived from principal component analysis. This model covers 84% of explained variance. An additive logarithmic model was chosen as the most advantageous. The calculated deterioration functions were proposed to be the priority aim of the IC Program - control of SO_2 effect. Other variants of the regression function may be optimal for other technical and scientific applications.
Keywords: Atmospheric corrosion, structural metals, effects of pollution, regression function, logarithmic model.

1 Introduction

International cooperative program UN ECE for evaluation of atmospheric pollution impact on materials including monuments was carried out on 39 sites of the participating countries between 1987 and 1995. Program provided a lot of data for derivation of relations to quantification of effects on materials.

SVÚOM Praha a.s., as fulfils function of a sub-centre for structural metals and so it focused on derivation of deterioration equations for these materials in the way that aims of the Convention of Long-Range Transboundary Air Pollution bodies are followed preferably.

2 Set of data

The input quantities are average values of corrosion losses and of environmental quantities for corresponding period. Corrosion effects were evaluated for 3 structural metals exposed in open air and sheltered conditions:

- weathering steel (Czechoslovak steel Atmofix 52 A, chemical composition according to Czech Standard: C < 0,12%, Mn 0,30 - 0,80% , Si 0,25 - 0,70%, P 0,07 - 0,15%, S < 0,04%, Cr 0,50 - 1,20%, Ni 0,30 - 0,60%, Cu 0,30-0,55%, Al < 0,01%),
- zinc (> 99,5%),
- aluminium (> 99,5%).

Basic climatic parameters (temperature, relative humidity, time of wetness and sunshine hours), concentration of gaseous pollution (SO_2, NO, O_3) and precipitation (amount, pH, conductivity, amount of SO_4^{2-}, NO_3^-, Cl^-) were measured on each test site. All data were reported to, and completed by the Norwegian Institute for Air Research -- NILU. Summarized environmetal data for period 1987-95 are in the report by NILU [1]. Parameters included for regression analysis are presented in Figure 1.

3 Derivation of the regression functions

3.1 Selection of the regression function type

We focused on an additive logarithmic model:

$$Ln(1 + CORR) = a + b.Ln(1 + SO_2) + c.Ln(1 + TOW) + \ldots$$

which can successfully substitute advantages of additional and multiplicant models and which is a result of the following analysis:

A. The linear model is probably the most useful simplification in a situation when the relations cannot be univocally substantiated.

B. Analysis of distribution of observed quantities (both corrosion and environmental) with the use of Shapiro-Wilk's test of normality [2] proved relatively strong deviations from the normal distribution in a high number of quantities.

That is why we transformed the quantities using Ln (1 + x) logarithmic function. Shapiro-Wilk's test of normality shows considerably better goodness of fit of the transformed quantities with a normal distribution.

C. If we use a logarithmic transformation of components in the linear regression model, we cover also the advantages of a multiplicative model due to the properties of a logarithmic function (Ln (XY) = Ln (X) + Ln (Y)).

3.2 Selection of regressors

If quantities showing a considerable degree of statistical interdependence (multicolinearity) are included into the model, it is obvious that:

- the risk of the regression function unstableness appears,
- weight of the influenceable SO_2 factor will be superimposed by other colinear factors.

Therefore we carried out an analysis of the structure of dependence between potential regressors (environmental factors), using the principal components analysis (PCA) with orthogonal varimax rotation [2]. The analysis was repeated

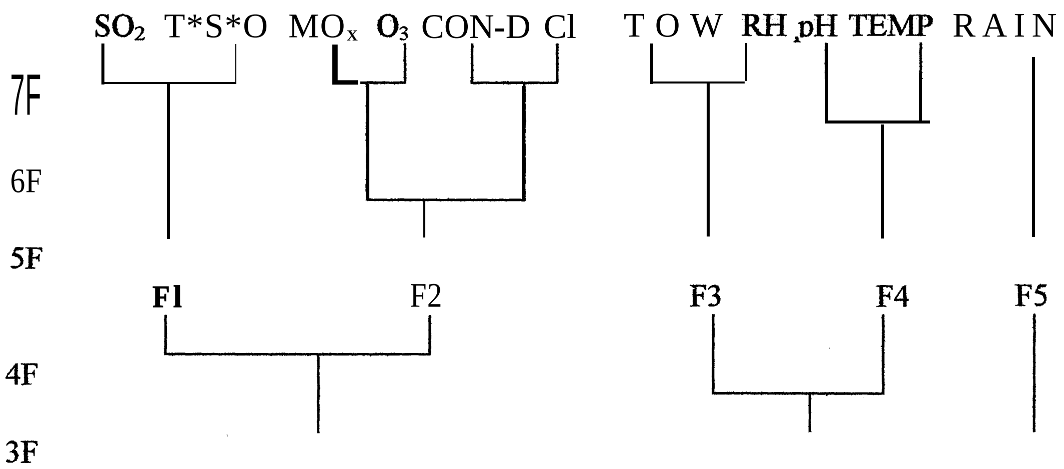
- separately for individual exposure periods (1, 2, 4 and 8 years),
- simultaneously for all four exposure periods, which a priori pointed out the variance of presupposed factors.

The input quantities are logarithms of the average values of environmental quantities for corresponding periods in Ln (1 + x) form.

To determine the primary number of extracted components - factors we have chosen the Kaiser-Guttman criterion [2]- the number of eigenvalues bigger than one. We gradually reduced the number of extracted independent factors (components) until the value of three. This way we obtained a tree-graph that describes the correlation taxonomy of individual environmental factors.

It is evident that the more independent the system of predictors is, the more stable the regression equation of deterioration will be. A five-factor model (including rain), which is pointed out in Figure 1, seems to be the most suitable one for our purposes. This model covers 84 % of explained variance in data space.

Figure 1 - Diagram for reduction of factors NOX COND



The general knowledge of atmospheric corrosion together with the results of the statistical analysis (pair correlation coefficients, partial correlation coefficients, stepwise regression analysis) prove that SO_2 and TOW are the decisive factors of corrosion. The question is what other quantities shall be included into the regression model to increase the predictability. But the aim is also not to decrease the reliability and stability of the model at the same time.

Issuing from the PCA results, the F1 factor is best represented by SO_2 regressor, also because we prefer the additive logarithmic model.

Potential representation of factors F3, F4, F5 is evident - TOW, pH, RAIN (although we do not suppose a significant effect of the fifth factor representative - the rain-fall amount). The problem of the second factor (F2) remains open.

We analyzed the question of involving ozone into, the regression equation of deterioration into detail. We calculated partial correlations - dependence of the corrosion rate on the ozone concentration (with fixed levels of other environmental effects) for these purposes. We calculated these partial correlations both for really observed values of ozone concentration (O_3), and for complete set with estimated values (O_3_n) based on NO, concentration. None of the correlation coefficients is significant, and they are even of negative values in about half of the cases. This fact proves a negligible influence of the ground-ozone in the process of atmospheric corrosion of the exposed samples. Therefore ozone was not included.

Another solution was focused on evaluation of suitability of involving the following regressors: conductivity, chlorides content, pH of precipitation. The basis were results of the stepwise regression analysis compared with generalized knowledge of atmospheric corrosion.

Modelling of the regression function during the stepwise regression analysis proves that involving another variable means a higher value of the determination coefficient in many cases, but at the same time, it also decreases the portion of the SO_2 effect (lower standardized regression coefficients and relatively higher standard fault of the regression coefficient) in the regression model in almost all cases.

The proposed solution does not follow the highest values of the determination coefficient, but the preservation of a sufficient importance of the SO_2 effect together with a relatively favorable determination coefficient value (Table 1).

Figure 2 and 3 present residuals and standard error of prediction of observed values from theoretical values resulting from the regresion model used. Sites with outlying values are evident too. It is obvious that addition of other regressors into the model does not represent a significant increase of its fitting which would make a more complicated model unambigously preferable to the basic one. The basic model brings significant advantages in practical use.

In case of equation designed for steel, it is always necessary to remember that exposed was a weathering steel that behaves in a different way than an ordinary carbon steel during longer exposures (about four years and more).

Detailed results are presented in report [3].

Table 1 - Results of regression analysis for model including SO_2 and TOW as regressors

Metal	LST_un_1	LST_un_2	LST_un_4	LST_un_8
Regression coefficients				
LSO2_1	0.255	0.217	0.173	0.144
LTOW_1	1.380	1.393	1.860	2.275
INTERCE	1.757	1.947	2.021	2.049
Standardized regression coefficients				
LSO2_1	0.687 ++	0.651 ++	0.522 ++	0.378 ++
LTOW_1	0.407 ++	0.464 ++	0.606 ++	0.663 ++
R-SQR	0.549	0.552	0.533	0.514

Metal	LST_sh_1	LST_sh_2	LST_sh_4	LST_sh_8
Regression coefficients				
LSO2_1	0.335	0.252	0.284	0.352
LTOW_1	1.536	1.278	1.605	2.151
INTERCE	1.294	1.692	1.776	1.779
Standardized regression coefficients				
LSO2_1	0.612 ++	0.594 ++	0.581 ++	-0.648 ++
LTOW_1	0.308 +	0.333 +	0.354 +	0.439 ++
R-SQR	0.410	0.407	0.393	0.534

Metal	LZn_un_1	LZn_un_2	LZn_un_4	LZn_un_8
Regression coefficients				
LSO2_4	0.105	0.256	0.251	0.284
LTOW_4	0.698	1.697	1.073	2.174
INTERCE	0.728	0.693	0,998	1.282
Standardized regression coefficients				
LSO2_4	0.391 +	0.575 ++	-0.697 ++	0.463 ++
LTOW_4	0.278	0.422 ++	0.322 ++	0.393 ++
R-SQR	0.193	0.439	0.514	0.319

Metal	LZn_sh_1	LZn_sh_2	LZn_sh_4	LZn_sh_8
Regression coefficients				
LSO2_1	0.144	0.188	0.186	0.206
LTOW_1	1.525	1.023	0.991	0.274
INTERCE	0.529	0.578	0.620	0.979
Standardized regression coefficients				
LSO2_1	0.327	0.557 ++	0.669 ++	0.577 ++
LTOW_1	0.363 +	0.325 +	0.364 +	0.081
R-SQR	0.200	0.360	0.476	0.320

Table 1 - Results of regression analysis for model including SO_2 and TOW as regressors continued

Metal	LAl_un_2	LAl_un_4	LAl_un_8
Regression coefficients			
LSO2_2	0.111	0.190	0.178
LTOW_2	0.672	1.271	1.186
INTERCE	0.008	-0.038	0.278
Standardized regression coefficients			
LSO2_2	0.430 ++	0.531 ++	0.522 ++
LTOW_2	0.289	0.382 ++	0.386 ++
R-SQR	0.233	0.358	0.367

Metal	LAl_sh_2	LAl_sh_4	LAl_sh_8
Regression coefficients			
LSO2_2	0.161	0.278	0.288
LTOW_2	0.900	2.758	2.721
INTERCE	-0.037	-0.224	0.064
Standardized regression coefficients			
LSO2_2	0.489 ++	0.509 ++	0.499 ++
LTOW_2	0.302 +	0.544 ++	0.523 ++
R-SOR	0.287	0.461	0.451

Note: example of marking in Table 1
LST_un_1 means logarithm of corrosion loss of weathering steel in open air after 1 year of exposure

As alternative regression functions were proposed functions with supplemental regressors (conductivity of precipitation for weathering steel, conductivity of precipitation and pH of rain for zinc, chlorides in precipitation for aluminium). Addition of regressors does not represent significant increase in fitting.

Figure 2 - Analysis of residuals and standard error of prediction for weathering steel exposed 8 years in open atmosphere

Model: $\ln(1 + CORR) = A + B_1 * \ln(1 + SO_2) + B_2 * \ln(1 + TOW) + B_3 * \ln(∓÷ COND)$

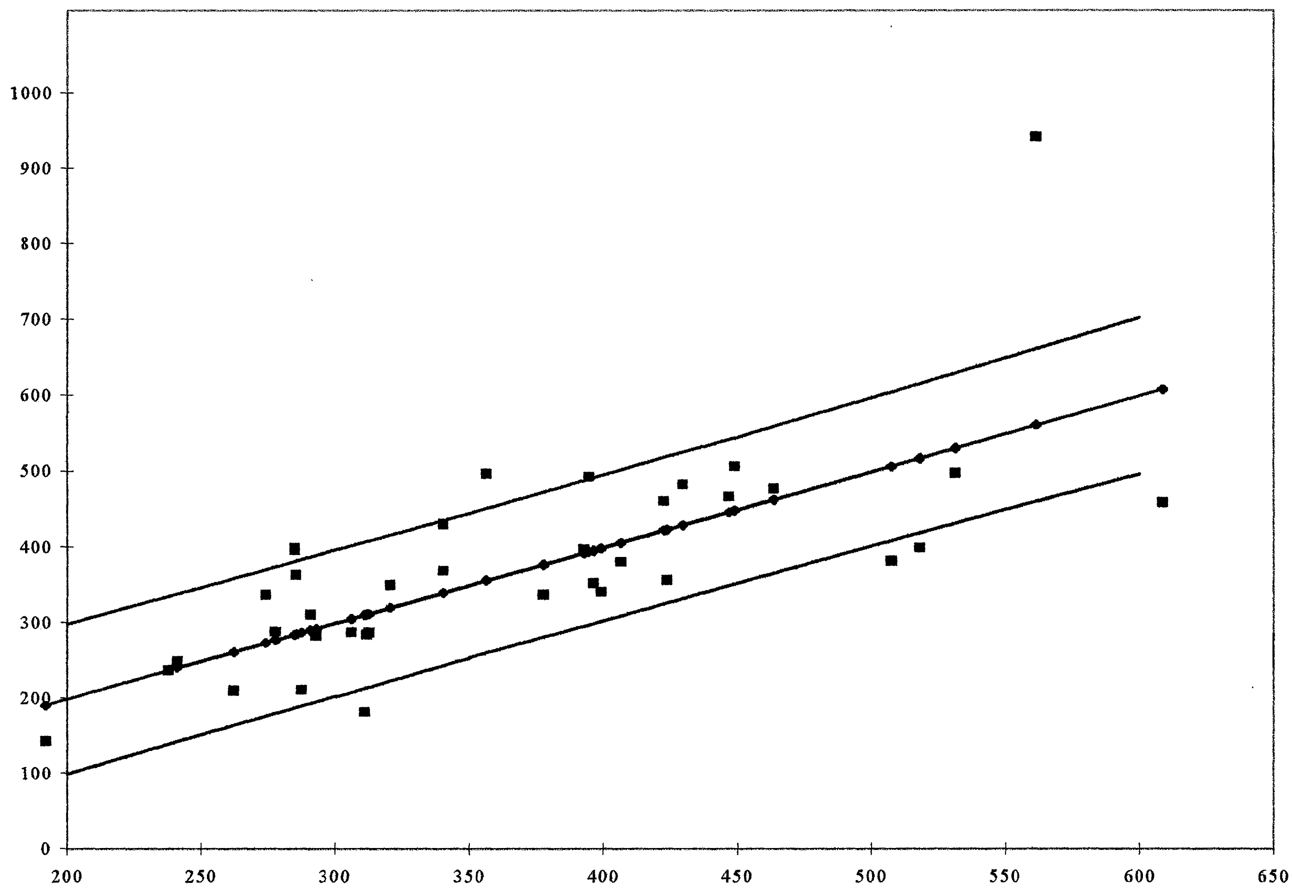
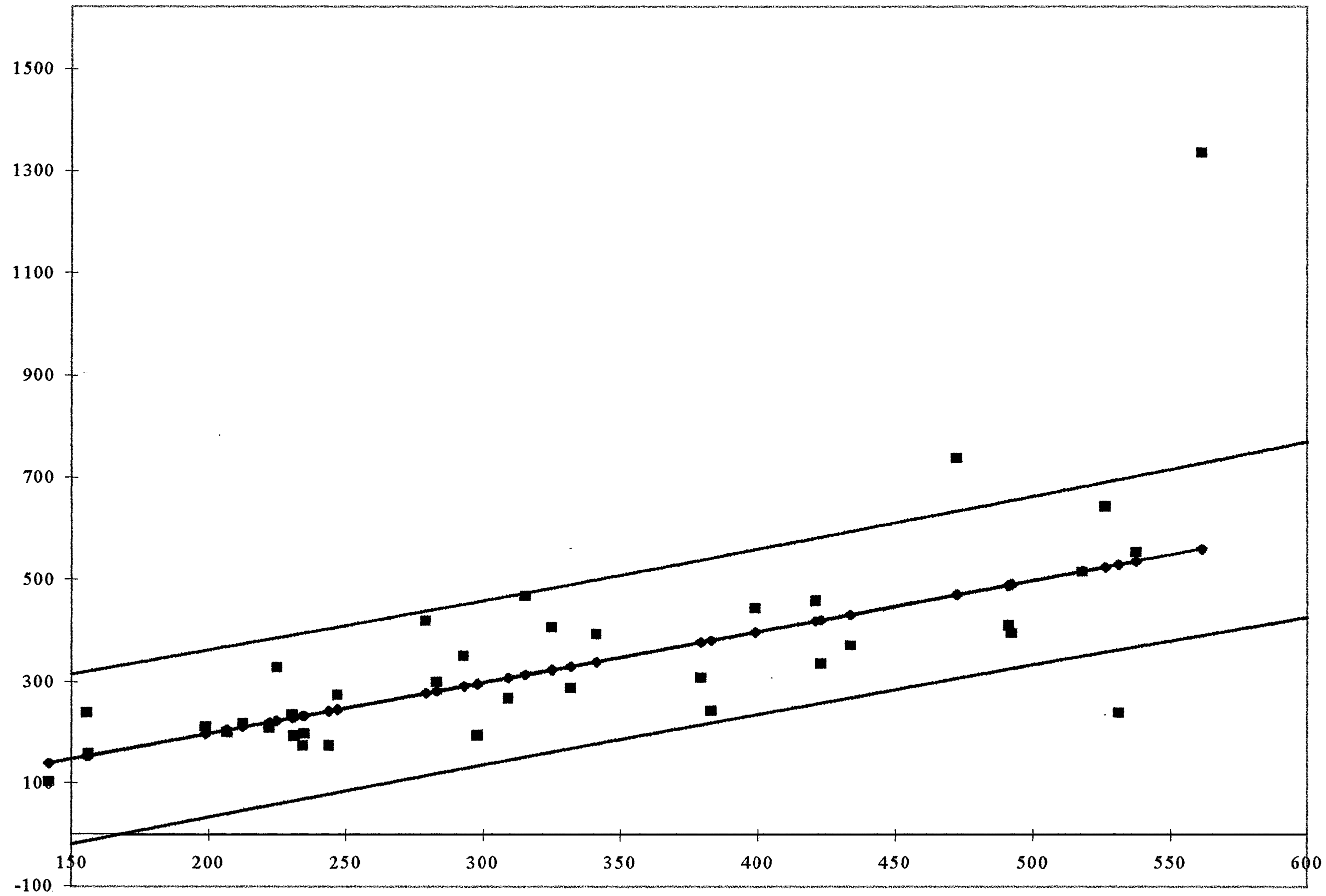


Figure 3 Analysis of residuals and standard error of prediction for weathering steel exposed 8 years under shelter

Model: $\ln(1 + CORR) = A + B_1*\ln(1 + SO_2) + B_2*\ln(1 + TOW) + B_3*\ln(1 + COND)$



4 Conclusions

Statistic analysis of corrosion and environmetal data led to following conclusions:

- an additive logarithmic model was choosen as the most advantageous
  - useful simplification in a situation of complicated relations
  - logarithmic tranformation of observed quantities shows better fit with a normal distribution
  - logarithmic transformation of components in a linear regression model covers the advantages of a multiplicative model.
- a five-factor model (Figure 1) was proposed as derived from principal component analysis (PCA). This model covers 84 % of explained variance in data space.
- regressors included in the calculated regression functions were derived with help of the stepwise regression analysis with the aim to reach relatively favourable determination coefficients but. to preserve a sufficient importance of SO_2.

In conclusion, it is necessary to repeat that the main way of using the proposed deterioration function is the control of SO_2 effect in the current stage. Addition of other variables increasing the multicolinearity of the model may lead to bigger inaccuracies in the model predictability. Other variant of the regression function may seem optimum for other purposes of use not only because of statistic analysis results, but also because of factors expressed in numbers.

5 Acknowledgements

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1. Henriksen, J.F. (1997) *UN ECE ICP Report No 2 1: Environmental data report.*, NILU, Kjeller
2. *BMDP Statistical Software Manual,* University of California Press, 1990
3. Knotkova, D., Kreislova, K., Boschek, P., Vlckova, J., (1997) *UNECE ICP Report No 22: Corrosion attack on steel, zinc and aluminium. Evaluation after 8 years of exposure,* SVÚOM, Prague

The construction industry and sustainable housing for the next 21st century: The eastern Africa case

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Abstract
Shelter is one of the basic needs of man. The 1948 United Nations Universal Declaration of Human Rights, the 1976 Vancouver Declaration on Human Settlements and the 1991 Global Strategy for Shelter to the year 2000; are among the few testimonials to this gracious price. However, even with the above mentioned declarations, still housing situation in many parts of the globe is not satisfying. The eastern Africa region is not exceptional, and housing can be generalized as non-sustainable. A practical solution is needed as the people are in acute need of decent, sustainable and affordable housing. By interpreting and applying modem building technology and expanding the old construction methods, basing on local conditions to suit the present need, a contribution towards sustainable housing can be made. Advanced and inherited building methods and technology, normally imported from industrialized countries, can systematically be studied, modified and integrated with the indigenous ones to provide sustainable housing. This can only be achieved by considering other co-related factors in the process including, affordability level, social factors and environmental issues. In this process, it is necessary to encourage and promote local construction industries. Importantly, governments' housing policy need to be constantly reviewed to cope with peoples' requirement and choice, and global changes. It is also worthy to study building technology and experience from other successful and applicable construction methods from elsewhere. Building materials should carefully be analyzed and applied properly.
Keywords: Building technology, building methods, construction industry, eastern Africa, government policy, materials technology, sustainable housing.

1 Introduction

Shelter is considered as one of the basic needs of man. This complies with the 1948 United Nations Universal Declaration of Human Rights, the 1976 Vancouver Declaration on Human Settlements and the 1991 Global Strategy for Shelter to the year 2000. In the UNCHS Habitat Report (1986), it is emphasized that: “human settlements are not simply housing or, for that matter, merely the physical structure of a city, town or village but an integrated combination of all human activity processes including residence, work, education, health, culture, leisure etc.; and the physical, structure that supports them” [1].

The whole world face housing problems, although in different levels and circumstances. However, in developing countries including east African countries, the situation is more uncertain than in the developed countries. Population growth is one of the contributing factors. By the year 2000, as mentioned in the Habitat report [1], eight out of ten people will be living in developing countries. Mitchell and Bevan [2], also summarize that, the real problem of housing provision in the developing countries in the last quarter of the 20th century is population increase.

It is true to mention that, the provision of shelter, and the steps taken by human being and society to satisfy the housing need has changed throughout our history. As such, there is a problem on the changes in methods of housing provision, because of an increase in the sheer scale of housing need.

When analyzing other factors associated to the housing problem including urbanization, planning controls and changing expectations, there is a need to consider the fact that, housing provision and the meeting of housing needs should not only be limited to increasing the number of housing units, but all the related issues which will result in providing sustainable and affordable housing [2].

2 The housing and construction sustainability concept

The working commission CIB W82 for the CIB “International Council for Building Research Studies and Documentation” launched a project on “Sustainable Development and the future of Construction” in 1995. In their report connected with the project, Bourdeau and Huovila [3], a definition (by Kibert and alii) for sustainable construction was introduced during the First International Conference on Sustainable Construction held in Tampa in 1994, as defined below:

2.1 The definition of Sustainable Construction

The creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles.

However, this definition is broad, and can be regarded as a base for individual countries or regions when formulating their own definition according to the local priorities.

3 Housing situation in the eastern African region

The main problem as is the case in most developing countries including eastern Africa, is the shortage of affordable housing. And the informal sector is largely responsible for housing issues, especially in low-income settlements. Figures presented by UNCHS [1] for Kenya as an example, indicate that, “the construction of traditional dwellings in 1976 contributed almost 60% of gross fixed capital formation, while the informal construction sector contributed around 30% to the gross domestic product (GDP) generated by construction between 1969 and 1978.

Despite its contribution to general development and the specific provision of affordable and sustainable housing for the majority i.e. the low-income majority, the informal sector enjoys few of the benefits of the formal sector [1].

3.1 Problems and the role of the government

The problems related to sustainable and affordable housing are in principle, similar in most developing countries (including east African region). They are discussed in brief as follows:

The housing problem is partly caused by the rural to urban migration. Population growth is also associated with this problem. As the migration take place parallel to population growth, the political, economic and social systems have been unable to keep pace. In addition, financing methods are not adequate and need to be established to serve the local private construction industries and the population for their housing needs. The question of cultural and social issues, and the participation of the local people which in most cases has been neglected need to be reconsidered.

The consideration of innovations in the materials and systems used in residential construction is not fully prioritized in most developing countries [4],[5]. It is difficult to use simple techniques, to improve tradition building methods. At the same time, local professionals and decision makers often oppose tradition materials and methods. As a result, the local users become reluctant, and aspire to development and high status, usually represented by modem building materials [6].

Government policy and programs concerning housing issues in many developing countries are still not sustainable. As discussed by Nguluma [7], in Tanzania during “the 1970s and 1980s, government efforts were not sustainable because of over reliance on capital intensive methods and no-involvement of the stake holders in the infrastructure improvements”. Further, “government efforts to upgrade infrastructure and services in unplanned housing areas were expensive and not sustainable because of, on the one hand over reliance on the inadequate public sector resources and on the other, gross disregard of private and popular sector resources and initiatives to improve their environments”.

3.2 Sustainable housing: Related issues

As discussed in (3.1), sustainable housing issues are mainly related to:

- The local population - people
- Financing
- Government policy and
- The (local) construction industry.

4. Priorities towards the 21st century

In order to meet the requirement of sustainable and affordable housing as we enter the 21st century, there is a need to prioritize our goals in a global perspective. As such, similar international approaches can be applied in different countries for finding local solutions and applications.

Such an approach is given by the CIB W82 project on "Sustainable Development and the Future of Construction" [3]. Basing on their formulated following questions on future sustainable construction i.e.,

- What kind of buildings will be built in 2010, and how we adapt existing buildings ?
- How shall we design and construct them ?
- What kind of materials, services and components will be used there ?
- What kind of skills and standards will be required ?
- What kind of cities and settlements will we have then ?

It is obvious that, this approach can be adapted in formulating the priorities of the east African region. However, there will be a need to define and modify the methodology of formulating these questions in order to match with the local need, as mentioned in this paper. Examples of such questions for the local region are:

- What improvements people want ?
- What is their order of priorities/ choices, and what resources can they contribute ?
- How can the optimization of residents participation be included ?
- Feasibility study on social, economic and technical questions need to be carried out. How can this be done ?

In an effort to formulate programs for global shelter (including east African region) strategy to the year 2000 and above, it is necessary to consider that, housing demand can be met in each individual country by applying a common set of global principles and approaches. There is also a need to reorganize the shelter sector. As emphasized in the Habitat report [8], "the key to effective national shelter strategies is macro-economic policies that link the shelter sector to the economy as a whole".

5 Summary and conclusions

From what has been discussed in this paper, the following conclusions can be made, for the achievement of sustainable and affordable housing in the region:

- It is clear that there is a great need of decent, sustainable and affordable housing in this region of the eastern part of Africa
- In order to make further progress concerning sustainable building in the region in the 21"' century, existing theories must be put to an action plan by parties involved in the process, governments and its agents playing the leading and supervising role

- If sustainable housing programs in the next 21st century need to be meaningful and make an impact in practice, local building industries must be totally involved in action programs
- Governments should secure that development programs assisting the needs of the people, including sustainable and affordable housing
- The governments should also pursue a course which enables people to cater for themselves, rather than attempting to solve the problems for them without including their own wishes/ choices
- A regular and systematically analysis need to be done by monitoring the trends in building materials and building technology development, in order to constantly cope with the local need and global changes
- And from what experience has shown, the only ones who have the capacity to alleviate the housing deficit are basically the people themselves; since it is for their own use and benefit that positive solutions must be found.

6 Acknowledgments

The authors wish to thank for the useful discussions, whether oral or through publications, and remarks from professionals/ institutions who are interested and involved in housing and sustainability issues. Their contribution have been very useful in this paper work. Also, the institutions where the authors are affiliated deserve to be acknowledged for any kind of support provided.

7 References

1. UNCHS (Habitat) (1986). Global Report on Human Settlements. Oxford University Press, Oxford.
2. Mitchell, M; Bevan A. (1992). Culture, Cash and Housing. Community and tradition in low-income building. VSO/ Intermediate Technology Publications, London.
3. CIB (1997). *Information Bulletin* Nr. 4/ 97 pp. 13-l 6.
4. CIB (1997). CIB Coordinators' Trend Reports. An anthology of Future Perspectives. W63 (Stroh, R. C.). *CIB Report.* Publication 211. CIB, Rotterdam.
5. Makenya, A. R. (1996). Building Systems for Affordable Housing in a Developing Country. *CIB W89 Beijing International Conference, 21-24 October, 1996. File:D:/ Papers/ 240 249/ 241/ P241.HTM*
6. SIDA. (1994). Construction in Developing Countries. A guide for the planning and Implementation of Building Projects Sida, Stockholm.
7. Nguluma, H. M (1997). Sustainable Human Settlements and Environment. In search of a strategy to improve Urban Infrastructure in Tanzania. M.Sc. thesis. Royal Institute of Technology, Stockholm.
8. UNCHS (Habitat) (1991). Global Strategy for Shelter to the Year 2000. UNCHS, Nairobi.

Earth as a wall material and its impact on pollution

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Abstract

Studies promoting earth as a construction material have been on going since 1978 at the Istanbul Technical University. The objective of these studies is to develop healthy and functional habitats for the growing population in this region and around the world.

The UN conference in Rio "Eco'92" encouraged to advancing earth construction advancing technology with the ecological diagnosis. It is well-known that earth construction creates a healthy indoor environment, as well as it preserves the world energy resources.

Housing is responsible for a significant proportion of energy consumption. Although there are few emission at the construction site, there may have been considerable emissions during the production of the building material as well as emissions brought about by operating and maintaining the building. The intensity of energy consumption impacts the use of the global resources. And the pollution, throughout the life cycle of the building.

Due to the high demand for housing after the World-War II. housing sector first aimed mass-production by the rationalisation and prefabrication. Next the effort was to improve the physical properties of building envelop and indoor climate, created by the materials and technologies those are industrialized products. Today the target is to sustain the biological life of humans by respecting the environment.

As one third of the world population is living in earth construction, research has been carried out to improve some of the mechanical and physical properties of traditional earth construction. These studies have shown, that stabilizing earth with 10 % gypsum and 2% lime brings advanlages to the material such as : unit weights of 1.4 t/m^3, compressive strenghts of 2-4 N/mm^2, low water absorption and shrinkage of about 1%, and values of heat conductivity of 0.4 w/m^2K.

World resources should be handled with care. Gypsum stabilized earthen building materials are suitable for mass produced housing. The physical properties of the material provides the construction industry with the following benefits: contribution to healthy housing, contributing to energy reductions, contribution to reduced pollution.

Key words : adobe construction, construction technology, earth construction technology, energy consideration, mechanization, pollution reduction, stabilization, wall material

1 Introduction

The whole environment, including the flora, atmosphere and sources of water should be protected for the survival of humans. This necessity has been signed by 154 countries during RIO I and RIO II Environment Conferences. The European Organization of Standards has published the standard (EN 832) relating to "Heat Capacity of Buildings, Calculation of Residential Energy Consumption" in CEN 1995.

Not only is the service life of housing threatening the ecological system and subsequently the human life trough environment pollution, but also entire life cycle, including: 1 .law material supply, 2. Material production, 3. Elements production, 4. Construction, 5. Service life, 6. Maintenance-repair, 7. Waste recycling stages. The research aims to contribute to preserve the natural resources by improving earth improving construction materials for the mass-housing. The reason that it very sound creates thermal comfort and is environment friendly during the construction stage, throughout the service life, as well as in recycling stage.

2 Objectives of the Housing Sector

After the end of World War II. the demand for housing increased due to the disaster, and also immigration and rapid population growth. This due to the problem was in past solved using industrialized construction technologies and prefabrication.

The next objective was to predict the physical conditions of new constructions, created by other then well known traditional materials. There after, mechanical air conditioning system were invented that required automatic control equipment and finally the age of "Intelligent Buildings" was reached.

The man-made conditioning systems are now considered to threaten the eco-system in dense settlements in addition to the industrial establishments. From these situations today's objective for "Healthy Housing" integration of [1] 1. The User's Health 2. Ecology 3. Affordability. as indicated in Table 1, today's housing objectives are focused on human and environmental criteria.

Table. 1 Objectives of the housing sector after the world wars.

1st Period (1945-) Rationalization	2nd Period (1980-) Intelligent Buildings	3rd Period (1990-) Healthy Building
Rationalization Industrialization Prefabrication	Automation of the mechanical supply for conditioning	1. User's Health 2. Ecology 3. Effordability

3 TUBITAK INTAG 622 T Research

The fact that the building industry consumes a large amount of energy and the wall material constitutes is the largest volume, reveals the importance of the wall, when focusing on issues of a healthy environment. The wall material effects the energy consumption by : 1. material production, 2. material transportation, 3. heating / cooling of the building.

Alker wall material, a short name of gypsum stabilized earth (gypsum=alçý, adobe=kerpiç), has been developed to consider the reduction of the energy. Alker

Alker wall material, a short name of gypsum stabilized earth (gypsum=alçý, adobe=kerpiç), has been developed to consider the reduction of the energy. Alker embodies less energy than other wall materials, it is locally excavated and needs a little transportation energy. A house constructed out of Alker has a low k-value, as indicated in Table 4 and Figure 1, thin enables a low consumption of energy for heating and cooling.

There are two main researches projects that have been supported by TUBITAK (The Turkish National Research Council) to promote the earth construction technology. The first project faund in report MAG 505 (1980) [2] is the basic research and provides information concerning to material properties, as shown in Table 2 and 3. The research TUBITAK INTAG 622 T (1995) [3] has been conducted for TOKI (Turkish Prime Ministry Housing Development Administration) to improve the workability and curing conditions of these materials. Result of same of this work that is focused on using the Alker technology for the mass production of housing, is provided in Table 3 and 5 below.

Table 2. General properties of alker

Reduces the water absortion
Improves the mechanical properties
Improves the heat insluation
Low shrinkage
Clean surface
Short setting
Short construction time

Table 3 Curing to obtain the required strength and durability

Traditional earth	ALKER construction
15-21 days Strengthening	20 min.
curing; area	no curing; area
water sprinkling	no water sprinkling
rain protection	no rain protection

Table 4 Physical Properties

Unit weight	1.6-1.7 kg/lt
Shrinkage	1.0-1.5%
Compressive strength	2.0-4.0 N/mm2
Shear strength	0.9-1.3 N/mm2
Water absorption	verv low
Long term water exposure (except direct rainfall)	no erosion
Heat transfer value	0.4-0.5 kcal/mhC
Specific calorific	1.0kJ/kgK

Table 5 Workability

Water Content	Workabilitv
18-29 %	rammed earth
20-22 %	adobe blocks
24 % and more	segregation

Considering the workability and the short curing conditions, an "Alker" building has been constructed in the University Campus, wiht the aim to determine the thermal properties of the new construction technology.

4 Thermal properties of Alker for healthy and eco- housing

If the difference between surface temperature and indoor air temperature is high, air circulation can effect the user's health. Difference between surface temperature and indoor air temperature should be ± 2 ^{0}C. As the heat insulation capacity of Alker material is high, difference will remain below the limiting value. In such cases, comfort conditions, necessary for human health are provided and savings in terms of heating load are achieved. Table 6 indicates temperatures of interior surfaces for various exterior wall materials for an outdoor temperature of -5 ^{0}C and indoor temperature of + 20 ^{0}C.

Table 6 Comparison of the indoor surface temperatures, by different wall material (Outdoor: - 5 ^{0}C, indoor: + 20 ^{0}C)

	Concert Wall	Full brick	Hole brick	Light weight concrete	Alker wall
Indoor Surface Temperature (^{0}C)	+ 9.68	+ 12.44	+ 13.70	+ 14.84	+16.80

A solid exterior wall made of Alker material can provide heat insulation at the desired level one layer (uninsulated). The cost of uninsulated exterior wall made of solid concrete remains below the cost of Alker material. However, its thermal conductivity is nearly 5 times greater than the Alker material. Depending on the material used, the heat conductivity of an exterior wall with no heat insulation increases the heating energy demand that also increases turn gas proportions and environmental pollution. The low capacity of heat conductivity of Alker keeps the air clean. To reach the same k-value of walls constructed by a material other then Alker an insulation layer is necessar, thins, necessarily increases the cost of the exterior wall. The above mentioned relationship between heat conductivity and environmental pollution, heat insulation and cost for various wall materials is given in Figure 1. The need for heating energy changes depending on the type of exterior wall. As indicated in Figure 4, a building with a 19 cm. solid brick wall will requires 10.000 kWh heating energy per year, whereas a building with an Alker wall of 45 cm. thickness, requires heating energy of 632,5 kWh per year. This indicates that using Alker material would provide a 40% savings in terms of heating energy. As heating energy consumption is one of the major

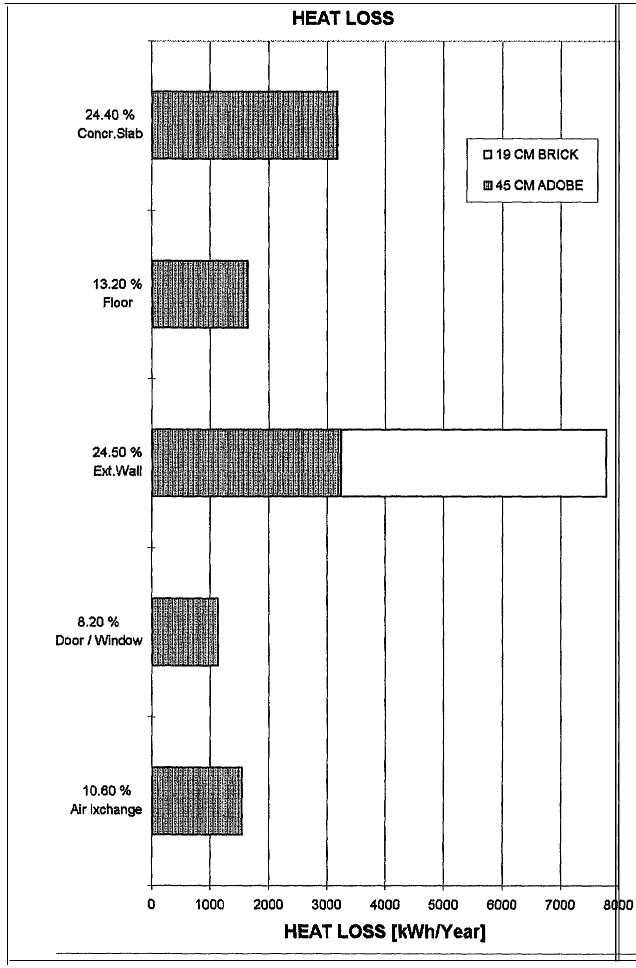

Figure 2 Heat loss

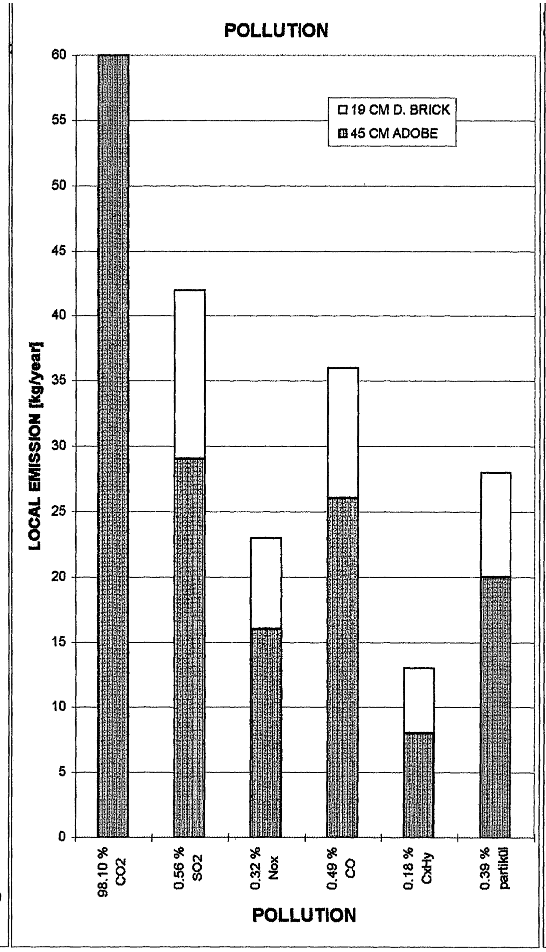

Figure 3 Pollution

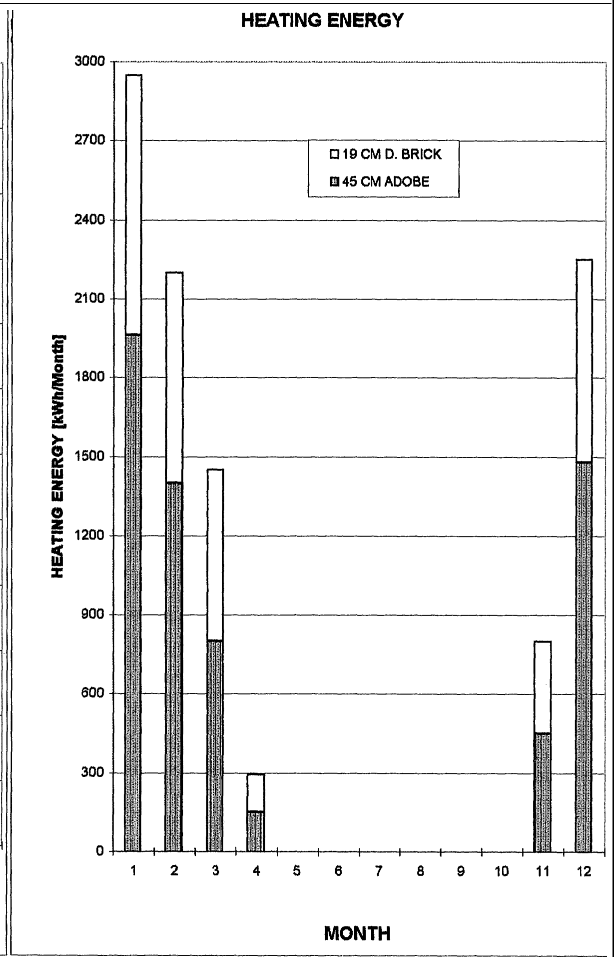

Figure 4 Heating energy

Figure 1 - Comparison of exterior walls

	CONCRETE WALLL	BURNED BRICK	LIGHT WEIGHT CONCRETE	ALKER BLOCK	COMPACTED ALKER
WALL PROPERTIES	20 cm	19 cm	20 cm	45 cm	45 cm
k VALUE W/m² K	3.23	1.25	0.95	0.7	0.7
PHYSICAL PROPERTIES	λ= 2.090 W / m² K γ =2400 kg/m³	λ=0.580 W / m² K γ =1400 kg / m³	λ=0.240 W / m² K γ =600 kg / m³	λ=0.40 W / m²K γ =1600 kg / m³	λ=0.40 W/ m² K γ=1600kg/m³
POLLUTION kg / yr.		CO_2 =7090 SO_2 =40.5 CO =35	CO_2 =5675 SO_2 =32 CO =27.5	CO_2 =5151 SO_2 =29 CO =25.5	CO_2 =5751 SO_2 =29 CO =25.5
COST WITHOUT HEAT INSULATION $ / m², 1995	3.3	9	9		4.4
INSULATION FOR EQUAL k=0.7 W/m² K	20 | 9	19 | 9	20 | 15	45	45
TOTAL WALL COST $ / m², 1995	11	14	12.9		4.4

factors for air pollution thermal conductivity value of exterior walls has to be reduced. The effect of 19 cm. exterior brick wall has been compared with the 45 cm Alker wall in terms of heat loss as shown in the Figure 2, using of Alker as wall material reduces the rate of pollution in the air by 30%, as shown in Figure 3.

5 Impact of the Alker construction on environmental pollution

The life-cycle of Alker material as in any other construction process consists of 1. Raw-material supply, 2. Material production, 3. Element production, 4. Construction, 5. Service life, 6. Maintenance-repair, 7. Recycling. A summary of the impact of Alker construction and the life-cycle of the Alker building on environmental pollution is given below:

1. *Raw Material Supply /Environment:* Construction of a building requires processing of raw material into construction material. During this conversion process, a different amount of energy is consumed for each particular material which leads to pollution of earth, atmosphere and sources of water. Procurement of raw materials for Alker only consists of excavating the proper soil and transportation of the same to that site, which causes no environmental pollution.
2. *Material Production / Environment:* Procurement, transportation preparation and molding of the raw material stabilized with gypsum do not require significant amount of energy. Kiln energy of the plaster and lime additives is lower, compared with cement, which provides both saving in terms of the national energy budget and reduced wastes.
3. *Elements Production / Environment:* Mechanical compacting of Alker in the formwork, takes a very short time. Preparation of mixer requires 2 minutes. Electrical power consumption is low. Construction materials manufactured with state-of-the-art technologies cannot adequately fulfill heat insulation, heat storage and humidity stabilization functions properly when used alone for construction of walls. Such functions require a separate material layer and additional labor for installation. However, Alker wall material meets such comfort requirements when used alone as a wall material.
4. *Construction Process /Environment:* The Alker construction technology is furnished with, the equipment such as mixer, band conveyor, mechanical compactor, etc. to save labor. Energy consumption is considerably low due to shortened process times brought about by the use of gypsum.
5. *Service Life / Environment:* Figure 2 and Figure 4 illustrates the reduced energy consumption (4(achieved during the service life of Alker buildings. Therefore, emission of pollutant solids and gases by Alker buildings is reduced by 30% shown in Figure 3. Savings in terms of national energy budget are achieved due to reduced energy requirements.
6. *Maintenance-Repair* / Environment: Maintenance and/or repair works are not as necessary which causes lower environmental loads.
7. *Recycling / Environment:* After demolishing of Alker wall, the waste material is biologically degradable to a full extent, or can be re-used as a construction material, if required.

6 **Conclusion**

"ALKER" walls constructed by gypsum stabilized earth material meet the requirements of healthy housing, without needing other layers thanks to its bearing, heat insulation, heat storage and vapor diffusion properties that provide considerable advantages in terms of environmental protection compared to the industrial construction materials.

References

1. **ANON** **(1993)**, *A World Conference On Advanced Housing For Energy-Efficiency and Environmental Responsibility, Final Report of the Conference,* "Innovative Housing' 93", National Research Council, Canada
2. KAFESÇIOGLU, R., TOYDEMIR, N., GÜRDAL, E., ÖZÜER, B., **(1980)**, *Stabilization of earth by gypsum, as a wall material*, Istanbul, TÜBITAK MAG 505
3. ISIK, B., *AKIN,* **A.,** KUS, H., GÖÇER, *C.* *(* **1996**), *Research for adequated mechanized construction technology for gypsum stabilized earth and contribution to the standardization*, Istanbul, TUBITAK INTAG 622
   TÜBITAK INTAG TOKI 622
4. KAFESCIOGLU, R. *(* **1987**), *Thermal Properties of Mudbricks, Amman, Expert Group Meeting on Energy-Efficient Building Materials for Low-Cost Housing.*

Performance requirements of building products derived from construction and demolition waste

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Abstract

This paper examines emerging trends in recycling of construction and demolition waste and its potential impact on the construction sector in Australia. Whereas concrete recycling for new construction and road pavement applications are rapidly gaining industry acceptance, progress with high level recycling of brick and general rubble remains comparatively slow. However, current initiatives toward performance-based specifications provide a basis for greater consideration of secondary materials. Data generated at CSIRO to evaluate the performance and application of plant recycled concrete is presented and discussed. The project findings highlight technical requirements necessary for the satisfactory performance of demolition waste within the framework of ecologically sustainable construction practices.
Keywords: Recycling; C&D waste; concrete; specifications; concrete aggregate; contaminants.

1 Introduction

Whilst a significant proportion of conventional demolition debris is currently recycled for use in low level fill applications, the need for higher value addition to materials such as concrete and brick is considered critical to improved recycling efficiency and better management of the construction and demolition (C&D) waste stock in Australia. Commercially, recycled concrete is rapidly emerging as a viable product with diversified construction applications [1–4]. This trend is largely driven by legislative instruments and rapidly emerging recycling industries. The current Australian government policy is to reduce waste destined for landfill by 50% by the year 2000 benchmarked to 1990 per capita levels.

This policy was published in 1992 as the National Waste Minimisation and Recycling Strategy, through the Australian and New Zealand Environment and Conservation Council (ANZECC) [5]. To achieve the objectives of the Strategy and the reduction targets set by the different states and territories would require rigorous adherence to waste minimisation principles.

Responsibility for waste management and for legal regulation of waste management lies with state, territory and local governments. In reality, the only legislative role played by the Commonwealth is to regulate the import and export of hazardous wastes under the Base1 convention.

Regional standardised methods and procedures to evaluate the potential environmental impact of recycled materials, including the quality of both input and output materials from C&D recycling facilities have begun to emerge. This includes draft specifications and local government policies for the use of recycled materials for low grade applications such as fill for road base, as well as draft guidelines to aid the specification of recycled concrete as aggregates in concrete construction [3]. These initiatives are reviewed based on laboratory assessment of the technical performance of commercially available recycled concrete aggregate (RCA) for both new concrete production and road base applications.

2 Background

About 14 million tonnes of solid waste per annum is presently generated nationally. Waste generated from refurbishment and C&D operations forms a significant proportion of this solid waste stream. Whilst a considerable proportion of demolition concrete is recycled, with the current national average in excess of 70%, other building materials such as bricks, windows and fittings are reused but on a much smaller scale. The rapid growth in concrete recycling over the last decade is demonstrated by the trends shown in Figure 1 for the State of Victoria, with similar volumes recycled in New South Wales. It is well recognised that to sustain this rapid growth rate depends largely on the creation of new markets and the promotion of recycled products.

Primary markets for crushed concrete such as foundations, bulk fill and retaining walls are rapidly being expanded to include high level applications such as graded aggregate for new concrete and landscaping.

Correspondingly, products and markets for recycled bricks currently appear to be restricted. Whilst the seconds market remains steady, consideration is now being given to the use of recycled bricks as a sub-base material for pavement applications.

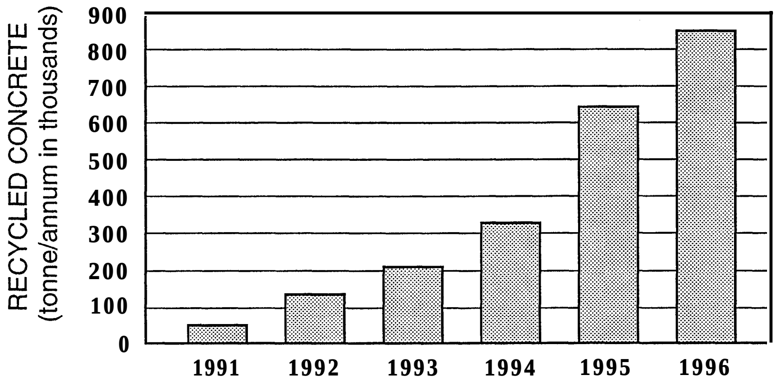

Figure 1. Tonnage of recycled concrete in the State of Victoria

Acceptability of recycled materials would eventually depend on meeting technical suitability and environmental impact requirements. In the case of RCA for concrete production, achieving satisfactory concrete performance largely depends on aggregate quality. Data generated from a pilot study of aggregates in the State of Victoria are presented.

3 Characterisation of recycled concrete aggregate

Currently, high level, high volume recycled material from demolition waste generally includes graded concrete aggregate, crushed masonry aggregates, crushed asphalt, sieve and crusher sand, a mixture of crushed concrete and masonry aggregates, crushed brick and recovered brick.

The results of a survey on properties of some commercially available RCA in are shown in Table 1. Aggregate sampling was carried out on unwashed RCA from production stockpiles in accordance with Australian Standard AS 1141.3.1. Weekly batches thus obtained were graded prior to determining their properties and impurity levels. Equivalent properties of basalt, which is widely used as natural coarse aggregate in concrete manufacture, are also included in Table 1.

Batch code	Impurity level (%)	Bulk density (AS 1141.6) (kg/m^3)	Water absorption (AS 1141. 6) (%)	Aggregate crushing value (AS 1141.21) (%)
C220797 (RCA)	0.4	2395	5.6	23.1
C290797B (RCA)	1.1	2392	5.7	22.3
C3 10797 (RCA)	0.7	2424	5.2	25.3
C040897B (RCA)	1.1	2456	4.8	23.7
C240797B (basalt)	0	2890	1.0	15.7

Table 1. Contaminant level and physical properties of coarse RCA and natural (basalt) aggregates

The results in Table 1 show total contaminant levels expressed as per cent by weight of sample. Contaminant levels typically less than 1.2% of total material weight are obtained. The relatively low levels of contaminants are matched by the comparative uniformity of measured physical properties of the aggregates. Whilst the need for extended sampling cannot be overemphasised, the results nevertheless disclose a high level of consistency and quality of the material examined. This trend can be partly attributed to the very high quality of feedstock and the screening standards of operators.

Average batch compositions were assessed on 10 kg sub-sample lots, by visual examination of the +4.75 mm fraction sieved in accordance to AS 1152. Table 2 shows sieve analysis of RCA and basalt aggregate. The test portions were oven dried to a constant mass and accurately weighed before sorting. Hand sorting of all foreign material was first carried out on the dried material, followed by wetting, to ensure complete identification and classification of all types of contaminants.

Coarse aggregates	Percentage of weight passing through sieve						
Maximum size (mm)	19	13.5	9.5	6.7	4.75	2.36	150 μm
RCA	100	91.4	28.7	7.6	5.4	4.2	0.5
Basalt	100	84	43.7	5.6	2.1	1.0	0.2

Table 2. Sieve analysis of coarse RCA

Figure 2 shows the distribution of the constituents of RCA batches investigated. The classified lightweight material consist of components with dry density less than 1950 kg/m^3.

As observed in Figure 2, the brick content of the contaminant fraction typically exceeds 50%. Most bricks are normally fired at high temperatures with relatively good dimensional stability and, as such, are potentially suitable for use as concrete aggregates.

The plaster mortar and gypsum-based components of the contaminants, however, warrant some attention despite their overall low levels, averaging 0.04% by weight of total RCA material.

A threshold sulfate content as SO_3, derived either from high sulfate content bricks or from adhering plaster mortar, necessary to induce sulfate attack in cement matrices is required. The use of alternative binders, typically sulfate-resistant cements or blended cements, is being investigated. The effect of all other components such as glass, metal, stone and plastics is considered relatively minor, given their extremely low proportions.

4 Guidelines: coarse RCA utilisation in new concrete

4.1 Material properties

Currently, draft proposals for specifications generally involve commercially produced coarse RCA material of uniform quality with particle density in excess of 2100 kg/m? Typically, contaminant levels, including brick and stony materials, are limited to no more than 1%, whilst general impurity content, comprising friable materials and materials

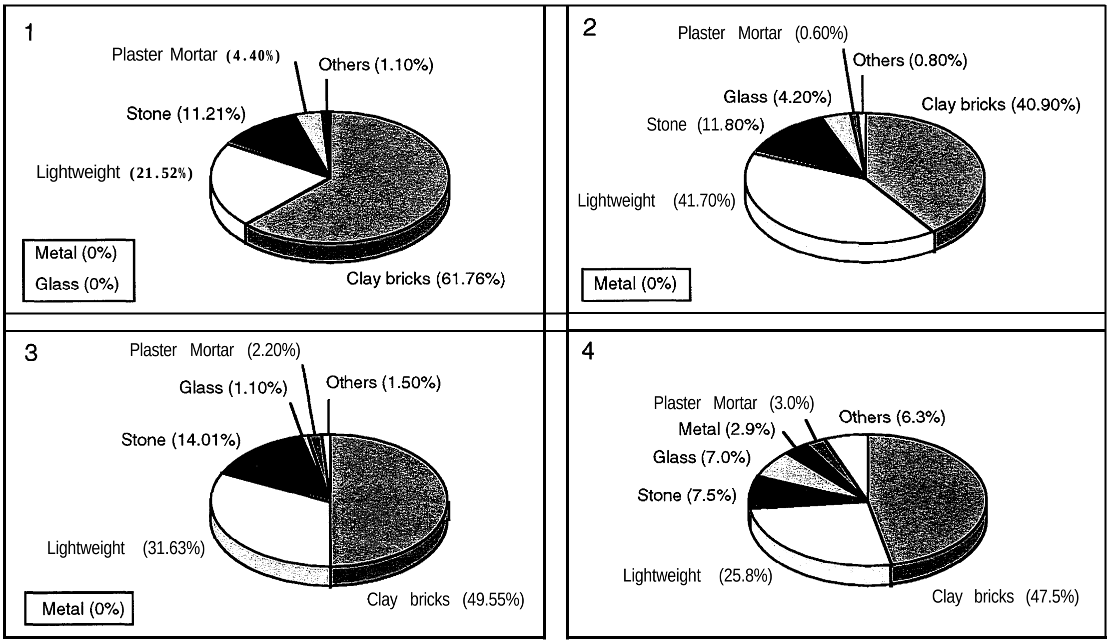

Figure 2. Detailed distribution of constituents of RCA batches

with density less than 1950 kg/m^3, is of the order of 10 kg/m? This class of aggregate may be deemed suitable for production of plain and reinforced concrete up to and including N32, i.e. 32 MPa grade concrete, with possible limits on RCA substitution levels. However, current trials at CSIRO generally disclose similar performance in both fresh and hardened states for fully substituted coarse RCA concrete and natural aggregate concretes with nominal 32 MPa compressive strength.

Whilst long-term tests are still in progress, similar durability characteristics are obtained in medium-term trials up to one year, except for variations in drying shrinkage performance. With the move towards performance based specifications (typified by AS 3600), i.e. fitness for purpose rather that conventional prescriptive specifications, it is anticipated that the RCA content in new concrete will only be restricted to cautionary recommendations for situations where limited technical data exists to support field performance.

Classifications for mixed crushed concrete aggregate and building rubble aggregate for concrete production are also being considered by road authorities, research organisations and local governments. Contaminant levels of these two categories are both limited to ≤5%, in addition to restrictions on maximum water absorption and grading requirements as per AS 1141. It may be expected that guidelines on aggregate quality will include technical detail on mix proportioning and concrete design parameters.

4.2 Guidelines: concrete performance

With regard to fresh concrete properties and concrete rheology, results from trial mixes involving commercial recycled aggregates indicate that premixing/prewetting of RCA in the concrete mixer improves workability of the fresh concrete without impairing the properties of the hardened concrete. The total water content of the aggregates therefore consists of the water contained in the pores of the particles and the free water. As with any concrete, it is the latter that strongly influences the workability, drying shrinkage characteristics and strength of concrete.

It is observed that for RCA concrete, the workability is sensitive to small changes in free water and the sand/aggregate ratio. Hence, achieving equivalent workability to natural aggregates requires a knowledge of the properties of the aggregate.

5 Guidelines: RCA utilisation in road pavement applications

Crushed, graded demolition waste is now widely considered suitable for use in lower layers of road pavement construction, subject to specified requirements. Since the key design criteria in road pavement construction is the performance of the base material under either bituminous or concrete pavements, aggregates for sub-bases and sub-grades must nominally provide uniform strong support and erosion resistance for the pavements. The grading requirements further allow for efficient use of materials with lower grade material at the bottom progressing to the highest quality material close to the surface.

The use of recycled concrete for sub-base preparation in both road and airfield pavement construction has evolved from satisfactory compliance with basic material specifications as summarised in Table 3.

Property	Specification	Test method
Bulk density	1200 kg/m^3	AS 1141.4
Particle density	**2000** kg/m3	AS 1141.6
Water absorption	≤6%	AS 1141.6
Material finer than 2.36 mm	≤3%	AS 1141.11

Table 3. Basic requirements of aggregate for road pavement applications

The requirements of Table 3 are generally supplemented with additional limits on aggregate crushing value, wet/dry strength, durability requirements, ease of compaction and material stability. Other key material properties of RCA generally specified in addition to those discussed previously may include maximum aggregate content, foreign materials content, grading and CBR.

Owing to additional plasticity requirements of different road authorities across the country, blending of RCA with natural aggregate is often required to meet tighter specifications; the proportion of RCA in such blends is generally limited to about 30%.

When cement and fly ash binders are used, both base and sub-base materials attract minimum cement content loading, with a proportion of the total cementitious material specified for fly ash typically no more than 20% for base applications. Restrictions on contaminant levels are marginally equivalent to those given in Table 3 but with limits on chloride and asphalt levels. The SO_3 content is restricted to 0.5 and 0.1% for base and sub-base materials respectively.

Since the presence of sulfates may affect long-term performance and durability of cement-bound systems, sulfate content of non-cohesive materials is nominally required to be less than 1% sulfate as SO_3 for engineered fill applications. As deleterious water-soluble sulfates require the presence of moisture to be harmful, this may be diminished by appropriate drainage or other barrier systems primarily for fill applications.

6 Conclusions

It is concluded that the key constraints to efficient recycling of C&D waste, as identified in this paper, are the control of material uniformity and the development of suitable performance specifications in line with AS 3600 in the case of concrete durability. To achieve this requires the development of quality criteria for recycled products and a review of existing specification.

The research further discloses that contaminant levels of commercially produced RCA is relatively low. This high quality is partly responsible for current initiatives to use RCA in premix concrete production to supplement applications in road pavement construction.

Whilst the potential for favourable high level applications of C&D waste remain, certain constraints restrict rapid entry of recycled products into existing markets in the construction sector. As discussed in this paper, progress towards performance-based specifications for RCA, tailored to specific applications, holds the key to increased product acceptance and new market development.

7 Acknowledgment

This authors gratefully acknowledge the financial support of EcoRecycle Victoria for the project.

8 References

1. Collins, R.J. and Atkinson, C.J. (1994) Specification and the use of wastes in construction in the United Kingdom, in *Environmental Aspects of Construction with Waste Materials*, eds J.J.M. Goumans, H.A. van der Sloot and Th.G. Aalbers, Elsevier Press, pp. 687-698.
2. Hansen T.C. (1992) *Recycling of Demolished Concrete and Masonry*, RILEM Report No. 6, E&FN Spon, London.
3. Sagoe-Crentsil, K.K., Brown, T., Mak, S.L. and Taylor, A.H. (1996) Engineering properties and performance of concrete made with recycled construction aggregates, Proc. National Symposium on the Use of Recycled Materials in Engineering and Construction, Sydney, Australia, 30-31 May 1996, pp 132-135.
4. Kasai, Y. (1994) Guidelines and the present state of the reuse of demolished concrete in Japan, in *Demolition and Reuse of Concrete of Concrete and Masonry*, ed. E.K. Lauritzen, E&FN Spon, London, pp. 71-81.
5. ANZECC (1992) National Waste Minimisation and Recycling Strategy, Australian and New Zealand Environment and Conservation Council, Canberra.

Properties of concrete incorporating fly ash and recycled demolition waste

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Abstract
High level replacement of natural virgin resources with secondary materials at all levels of construction provides a unique platform for the efficient management of the solid waste burden. This step, however, requires the development of binders that are tolerant to chemical and physical contaminants characteristic of the solid wastes. The properties of blended cements indicate that given appropriate mix designs, such binders can significantly enhance the properties of concrete and concrete products derived from demolition waste. Blended cements may comprise of Portland cement and industrial wastes, typically blast furnace slag, silica fume or fly ash from coal-fired power stations.

Performance tests have therefore been carried out on the properties of fresh recycled aggregate concrete incorporating fly ash. The results indicate significant improvement in both concrete slump retention and setting characteristics. Also, concrete durability, including permeability and compressive strength, are marginally affected. These findings suggest that higher levels of fine and coarse recycled aggregate replacement in new concrete are achievable with the use of secondary cementitious materials for non-structural applications.
Keywords: Concrete; aggregate; recycling; fly ash; durability; compressive strength; fines.

1 Introduction

The effective use of recycled materials and products remains central to current efforts aimed at optimising available natural resources in building and construction. Globally, the prospects of replacing natural quarry products with recycled concrete aggregates (RCA) in premix concrete production, for specified applications, is rapidly gaining acceptance [1]. This strategy offers clear economic and environmental benefits. In recent years, several studies have been conducted to demonstrate the viability of RCA as a source of quality construction material for use in concrete production [2, 3]. Furthermore, with the fines fraction accounting for up to 40% of the total weight of crushed rubble, there is an obvious need to use as much of this material as possible. However, the implications of RCA properties on mix design and concrete performance appear to be much less established.

This paper evaluates both rheology and the performance of RCA concrete containing significant loadings of RCA fines and fly ash. The ultimate goal, firstly, is to ensure satisfactory use of RCA and, secondly, that concrete structures are designed and constructed in such a way as to serve as a vital source of valuable recyclable material.

2 Experimental

Two separate batches of RCA fines and a single source of commercial-grade coarse RCA were used in the concrete mixes. The mix proportions were designed to provide concrete mixes with a nominal Portland cement content of 325 kg/m^3. The fly ash component was batched as a supplementary addition to the fine sand content rather than as a binder supplement. Fly ash was added to mixes to assess possible improvements in fresh concrete cohesion and workability.

The water/binder ratio of all mixes were adjusted to achieve comparable consistency and, hence, equal nominal slump of 80-t-10 mm. Reduction in the water requirement of mixes was attained by using a water-reducing admixture at the manufacturer's recommended dosage level.

Specimens were cast for compressive strength and shrinkage and cured as required under standard conditions. Table 1 shows the mix details of concrete specimens prepared, with the reference mix designated C2108A. Two sets of specimens were investigated – the first to evaluate the effect of natural fine sand replacement with recycled fines, and the second to evaluate the role of fly ash addition on concrete properties.

2.1 RCA properties

The properties and requirements of crushed concrete for use as concrete aggregate are similar to those of natural aggregates. This includes quality and grading requirements, as well as cleanliness and limits on deleterious matter that could affect the setting and durability of the concrete. Compliance of RCA to strength requirements, flakiness and permissible fines content was closely monitored to ensure satisfactory aggregate performance. Tolerance limits of chloride and sulfate are, however, yet to be established, as well as the potential for alkali-silica reaction. Table 2 shows results of sieve analyses of RCA fines used in the study.

Mix designation	Cement loading (kg/m^3)	W/B	Natural coarse (%)	Natural fines (%)	RCA coarse (%)	RCA fines 1 (%)	RCA fines 2 (%)	Fly ash (%)
C2108A	325	0.56	100	100	—	—	—	—
C2108B	325	0.61	100	—	—	100	—	—
C0712B	325	0.56	—	—	100	50	50	—
C0712C	325	0.51	—	100	100	—	—	—
Fly ash trials								
Cl101A	325	0.60	—	50	100	—	50	—
Cl101B	325	0.56	—	60	100	—	50	—
Cl101C	325	0.57	—	50	100	—	50	10
Cl101D	325	0.77	—	—	100	—	100	20

Table 1. Mix details of concrete specimens

Fine aggregates	Percentage of weight passing through sieve							
Max. size (mm)	30	25	20	9.5	6.7	4.75	2.36	150 μm
	100	100	100	95-100	95-90	80-90	65-80	48-65

Table 2. Sieve analysis of RCA fines

3 Results and Discussion

Significant variations in the fresh and hardened properties of concrete were observed with changes in the proportion and type of RCA fines introduced to the mix. The extent of bleeding of fresh RCA concrete mixes was significantly lower compared to control mixes of equivalent workability, although setting characteristics remained comparable.

Fresh RCA concrete properties and concrete consistency, as determined by the slump test and setting characteristics, have been investigated and found to be generally comparable to control mixes. For instance, laboratory test results on the setting behaviour of RCA based on the penetration resistance tests (Proctor needle) give values of initial and final set as 3 12 and 427 minutes respectively, corresponding to 3 18 and 406 minutes for control specimens made with natural aggregates.

Whilst changes in fresh concrete properties were relatively less pronounced, corresponding modifications to the hardened concrete were more readily measurable. Results obtained from concrete compressive strength and shrinkage characteristics have therefore been used to index the impact of RCA proportioning on concrete performance.

3.1 Compressive strength

Compared to the control mix made from natural materials, a reduction in the compressive strength of RCA concretes was observed at all ages. The compressive strength of concrete mixes up to 91 days are shown in Figure 1. Generally, the rate of strength gain is similar for all concrete mixes regardless of the source and type of aggregate used. The absolute strengths of the different mixes are, however, dependent on both type and

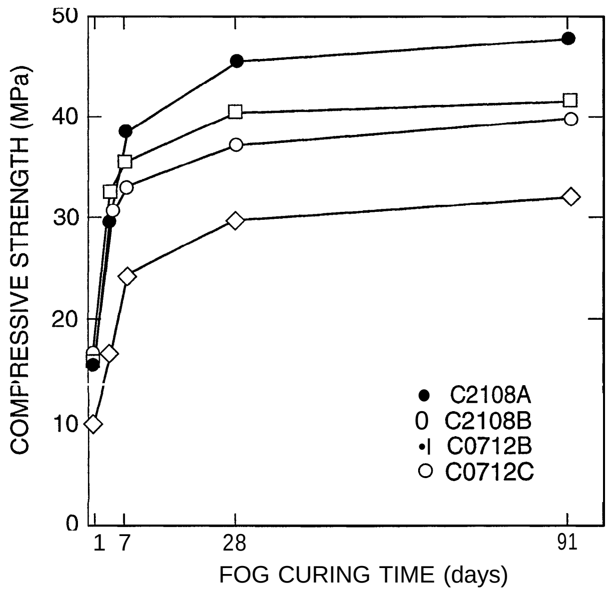

Figure 1. Compressive strength of control and RCA concrete

quantity of aggregate incorporated in each mix. This trend in strength development is further dependent on the proportion of RCA fines.

As shown in Figure 1, a 12% strength reduction is observed at 91 days when natural fines are replaced with RCA fines 1, i.e. mixes C2 108A and C2 108B. Only marginal differences in strength were observed between concretes made with RCA fines 2 and RCA fines 1.

The compressive strength of concretes made with 100% coarse RCA, but containing 50% natural fines, 50% RCA fines, and 100% natural fines respectively were relatively similar. Previous tests, however, have shown that this difference can be as high as 40% [3]. This latter result suggests that the hardened properties of concrete may be significantly influenced by both quality and grading of RCA fines.

The overall strength reduction of the RCA concretes range from about 13% for concretes containing coarse RCA and natural fines, to 32% for mixes containing only RCA materials. Such characteristic strength reductions are in line with published results [1, 4]. This trend is to be expected given that the water demand of RCA concrete often exceeds the requirements of normal aggregate concrete, particularly for mixes including RCA fines, as shown in Table 2.

3.2 Correlation between RCA properties and concrete strength

The strength of RCA concrete primarily depends on the strength of the cement paste and on the bond between the paste and aggregate. The strength of the aggregate also exerts some influence on the strength of the concrete [2], but this is nominal for most normal weight aggregates.

The bond between RCA and the surrounding matrix is influenced by the mineral composition, cleanliness, surface texture, and particle size and shape of the aggregate. Given that cement paste normally bonds better to a rough surface than a smooth or friable surface, residual coatings of clay or carbonated cement dust which adhere to RCA after mixing will alter bond properties.

Surface coatings on RCA generally tends to increase the quantity of fines in the mix and hence water requirements. Furthermore, adhering coatings impair the bond between aggregate and the cement matrix, and consequently the load transfer characteristics, resulting in overall strength reduction.

The quantity of residual fines in the mix, generated either from abrasion of the RCA during the mix or due to improper grading, has the potential to increase water demand. Therefore, within limits, mix proportions should be adjusted to compensate for potential changes in the grading of RCA fines during the mixing process.

3.3 Partial replacement of RCA fines with fly ash

Figure 2 shows plots of the compressive strength development of concrete containing different proportions of RCA fines and additional loadings of fly ash. At 10% additional fly ash loading to the fines content, only a nominal 7% drop in the **9** l-day compressive strength is obtained compared to the control made from totally natural materials. At 20% fly ash loading, the corresponding strength reduction is of the order of 25%.

The pozzolanic properties of fly ash significantly contribute to the later-age strength properties of the concrete, as indicated by the relatively rapid rise in concrete strength between 28 and 9 1 days (Figure 2). Additionally, other durability properties of RCA concrete are likely to be enhanced with the introduction of fly ash. In particular, reduced permeability may be expected [4].

The role of RCA fines in concrete strength development requires further examination with partial replacement of RCA fines with fly ash. In general, significant improvements can be achieved with the inclusion of fly ash as part replacement of the binder. Thus, when fly ash is included as part of the total binder, the optimum loading characteristics would be expected to increase significantly beyond 10%.

4 Shrinkage

The dimensional stability of RCA concrete is critical to satisfactory design in most areas of concrete construction. Figure 3 shows the dependence of concrete drying shrinkage

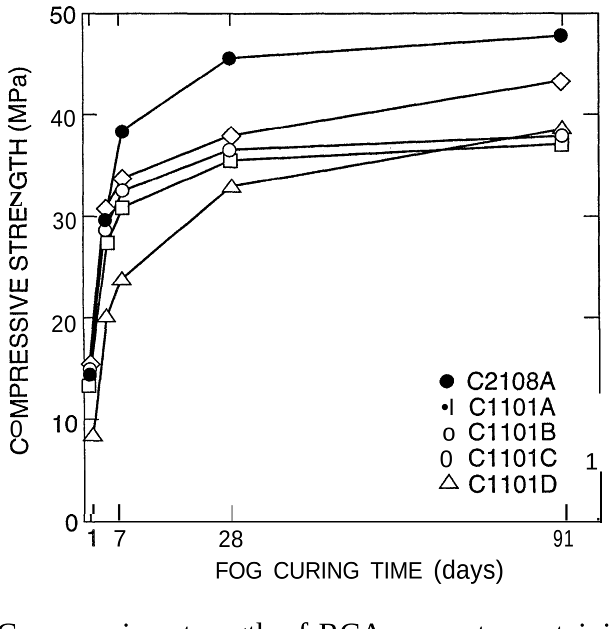

Figure 2. Compressive strength of RCA concrete containing fly ash

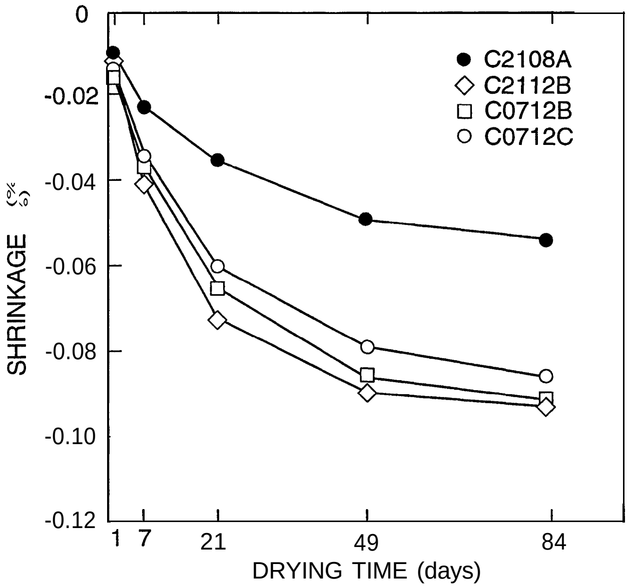

Figure 3. Drying shrinkage of RCA concretes

on RCA fines loading and, hence, water demand of the respective mixes. Compared to the control, shrinkage values recorded for concrete made with RCA coarse and fines at 91 days were 50% higher than control. Part replacement of RCA fines with natural fines marginally affected the shrinkage levels. These findings highlight the sensitivity of concrete drying shrinkage to RCA fines loading in the concrete mix.

It is evident from the results obtained that RCA fines have a significant influence on the drying shrinkage of concrete. This influence largely depends on the extent to which aggregates alter the water content of the concrete. Other RCA properties such as surface texture, grading, particle shape, proportion of fines and maximum aggregate size contribute to different extents to the drying shrinkage of concrete. It is essential also to monitor the absorption of RCA, since excessive absorption rates may produce concrete with very high shrinkage, especially for aggregates contaminated with clay fines.

Figure 4 shows drying shrinkage plots of the control mix and mixes incorporating fly ash. Comparing the shrinkage values of Figure 3 to those of Figure 4 indicates that variations in mix constituents have negligible impact on the overall magnitude of shrinkage for mixes containing RCA fines. It must be recalled that only marginal differences exists in the water to binder ratios of the mixes (Table 2). This trend suggests that while fly ash inclusion in mixes significantly alters later-age compressive strength, there appears to be no corresponding beneficial effect with regard to the drying shrinkage of RCA concrete.

From the shrinkage plots, it is further apparent that significantly higher shrinkage values are obtained for the RCA mixes with or without fly ash. The higher shrinkage values may be linked to the water content of RCA mixes, owing to the presence of excess fines. Thus, it is essential to establish an optimum fines content. Exclusion of RCA fines in concrete mixes has also been proposed in order to control excessive shrinkage [1]. However, the exact role of RCA fines on concrete performance may require further study, specifically the implications of grading and quality of such fines on concrete drying shrinkage and durability.

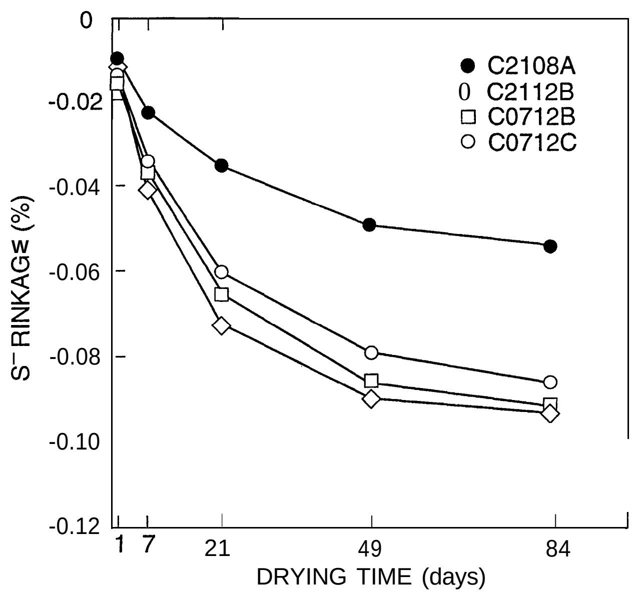

Figure 4. Drying shrinkage for RCA concrete containing fly ash

5 Conclusions

It is concluded from this study that although several fresh and hardened properties of concrete are altered with the use of RCA in concrete, the potential exists to offset some of these deficiencies through proper selection and grading of recycled materials and concrete mix design. The results further indicate that the compressive strength of RCA concrete may be enhanced with the addition of about 10% fly ash to the concrete mix. No corresponding benefits in concrete drying shrinkage were observed.

The extent of bleeding of fresh RCA concrete mixes was significantly lower compared to control mixes of equivalent workability, although setting characteristics remained comparable. However, owing to higher absorption rates of RCA fines, and consequently higher concrete drying shrinkage values, the use of RCA fines should only proceed with due caution and perhaps be limited to specified applications.

6 References

1. Hansen, T.C. (1992) *Recycling of Demolished Concrete and Masonry,* RILEM Report No. 6, E&FN Spon, London.
2. Frondistou-Yannas, Y.A. (1980) Recycled concrete as new aggregates, in Progress *in Concrete Technology,* CANMET, Energy Mines and Resources Canada, Ottawa, pp. 639-684.
3. Sagoe-Crentsil, K.K., Brown, T., Mak, S.L. and Taylor, A.H. (1996) Engineering properties and performance of concrete made with recycled construction aggregates, Proc. National Symposium on the Use of Recycled Materials in Engineering and Construction, Sydney, Australia, 30-3 1 May 1996, pp. 132-135.
4. Mehta, P.K. (1986) *Concrete, Structures, Properties and Materials,* Prentice Hall Inc., Englewood Cliffs, New Jersey, pp. 231-233.

The Potential for Solar Powered Desiccant Cooling

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Abstract
The air conditioning industry has, in recent years, come under sustained attack from a range of economic, environmental and regulatory pressures. Global environmental concerns, improving standards of ventilation and increasing concerns about indoor air quality have all contributed to a sea-change in design thinking. Professional guidance is increasingly steering clients and consultants away from full air conditioning to natural ventilation and mixed mode solutions in new and refurbishment projects. Nevertheless inefficient lighting, increases in computing equipment, and architectural fashion mean that overheating is now the predominant design consideration for new offices in the UK. Older buildings often constrain natural solutions. The situation is likely to worsen if global warming scenarios are accurate. It is vitally important that the building industry seeks innovative methods of maintaining and improving the quality of the indoor environment, under potentially more demanding performance criteria, without increasing the environmental impact. Solar air conditioning potentially offers an elegant exemplar of a clean, sustainable technology which is consistent with UK and International commitment to Sustainable Development. By using solar/gas hybrid desiccant cooling and dehumidification technology it may be possible to offer a benign solution to cooling of buildings, in new as well as refurbishment situations, and significantly reduce greenhouse gas emissions. Desiccant cooling is a potentially environmentally friendly technology which can be used to condition the internal environment of buildings. Unlike a conventional air conditioning system which relies on electrical energy to drive the cooling cycle, desiccant cooling is a heat driven cycle. The feasibility of solar desiccant cooling in the UK is examined in this paper; an investigation on the possibility of using solar energy to drive the desiccant cooling cycle is conducted. Through the use of a parametric study, the energy consumption and costs associated with desiccant cooling are evaluated.
Keywords: desiccant cooling, heat driven cooling, heat powered cycles, solar

1 Introduction

Desiccant materials such as silica gel have long been used to dehumidify air. In such processes, moist air is passed over a surface which is coated with the desiccant substance. As the moist air passes across the surface the desiccant material absorbs moisture from the air, thus dehumidifying the air stream. In order to drive off the moisture absorbed by the desiccant surface, the desiccant then has to be physically moved into a dry hot air stream. In the case of desiccant wheels (one of the most commonly used desiccant systems), the moisture laden section of the wheel slowly rotates (i.e. at 16 revs/hour) from the moist air stream to the hot dry air stream where it is dried out in a process called 'regeneration'.

In a typical desiccant cooling system a desiccant wheel is coupled to a thermal wheel in a single air handling unit (AHU), to produce a system which is capable of heating, cooling, and dehumidifying air, with little or no need for refrigeration [1]. Because it is a heat driven cycle, such a system has the potential to reduce both energy costs and environmental pollution, when compared with conventional vapour compression based systems [2]. Electrical energy consumption is replaced by heat consumption, which in most countries produces much less carbon dioxide (CO,). In the UK the burning of natural gas in a boiler produces 0.21 kg CO_2/kWh whereas delivered electricity produces 0.68 kg CO_2/kWh [3]. In addition, the significant reduction in size, or elimination, of refrigeration plant, results in reduction in the refrigerant charge required. Desiccant cooling affords an opportunity to utilise waste heat and the regeneration temperatures required mean that theoretically they could be coupled to solar collectors to produce an extremely benign cooling system.

2 The system

A typical desiccant cooling system is illustrated in Figure 1, and comprises a thermal wheel and a desiccant wheel located in series. On the supply air side of the AHU, a cooling coil and/or an evaporative cooler is located after the thermal wheel. A heating coil may also be located after the thermal wheel, for use in winter time if required. An evaporative cooler is located in the return air before the thermal wheel to enhance the heat transfer across the wheel. For the purpose of driving the cycle and regenerating the desiccant wheel a heating coil is located between the thermal wheel and the desiccant wheel.

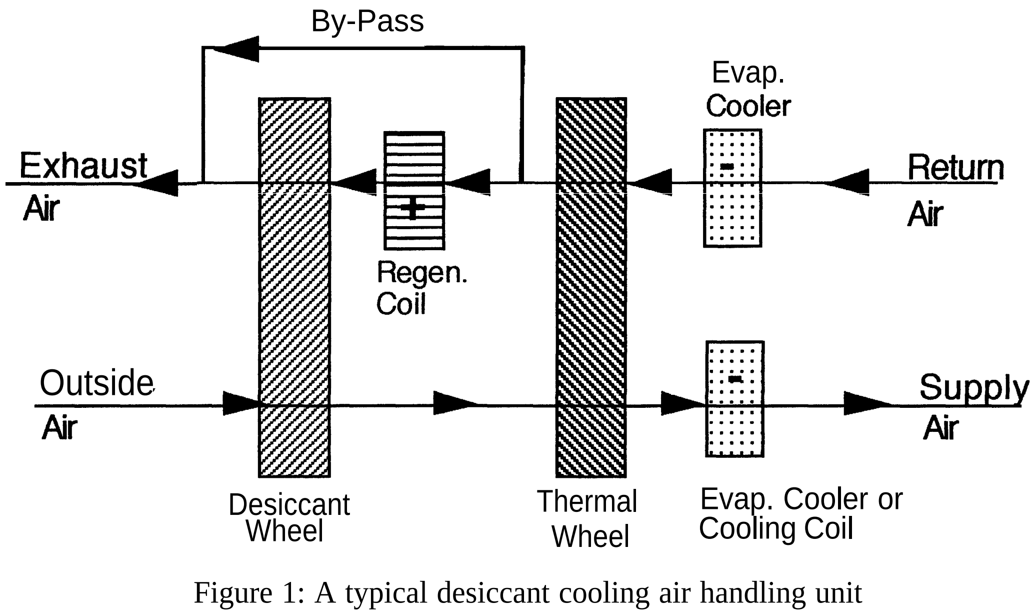

Figure 1: A typical desiccant cooling air handling unit

The cooling/dehumidification process is illustrated by the psychrometric chart shown in Figure 2. During the summer time, warm moist air at for example 26°C and 10.7g/kg moisture content is drawn through the desiccant wheel so that it comes off at say, 39°C and 7.3g/kg moisture content. The psychrometric process line for the air passing through the desiccant wheel on the supply side, has a gradient approximately equal to that of a wintertime room ratio line of 0.6 on the psychrometric chart. The supply air stream then passes through the thermal wheel where it is sensibly cooled to say, 23°C. The air then passes through a small direct expansion (DX) or chilled water cooling coil and is sensibly cooled to the supply condition of say, 17°C and 7.3g/kg moisture content. It should be noted that if humidity control is not required in the space, then the cooling coil can be replaced by an evaporative cooler with an adiabatic efficiency of approximately 85%. In which case, air may be supplied to the room space at say, 16.2°C and 10.2g/kg moisture content.

On the return air side, air from the room space at for example, 22°C and 8.6g/kg moisture content is first passed through an evaporative cooler so that it enters the thermal wheel at approximately 16.2°C and 10.8g/kg moisture content. As the return air stream passes through the thermal wheel, it is sensibly heated to approximately 35°C. The air stream is then heated up to approximately 55°C in order to regenerate the desiccant coil. It should be noted that in order to save energy approximately 20% of the return air flow by-passes the regenerating coil and the desiccant wheel [4].

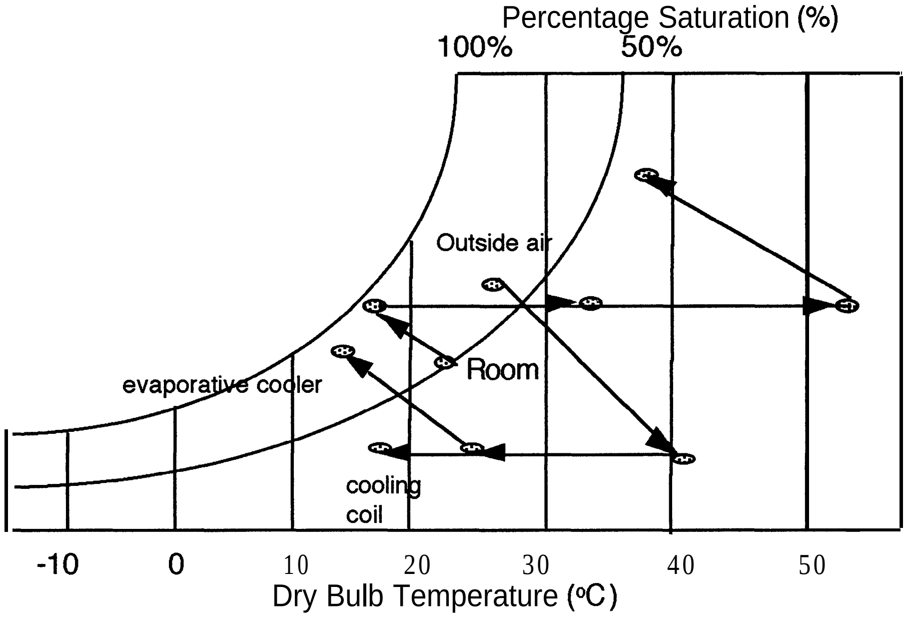

Figure 2: Desiccant system in cooling/dehumidification mode

3 Evaporative cooling

Through the use of a desiccant cooling air handling system it is possible to both dehumidify and sensibly cool the fresh-air supply. However, this often requires the installation of a chilled water cooling coil in the supply air stream. Whilst the installation of a cooling coil might result in an overall energy saving, the downside from the environmental perspective, is the introduction of refrigerants into the system. It is possible to avoid the use of a cooling coil, by installing an evaporative cooler in the supply air stream, to provide the required sensible cooling. However, this strategy has two major drawbacks:

- The air supplied to the room space is humid. Consequently, although the system might achieve the required degree of sensible cooling, it may not be able to provide adequate latent cooling, with the result that the occupants may find the environment uncomfortable. In addition, the high humidity in the room space is likely to lead to condensation problems.
- In order to achieve the required degree of sensible cooling, it is often necessary to perform a large amount of dehumidification on the desiccant wheel. This high level of dehumidification necessitates a high regeneration temperature, and consequently the energy consumption is increased dramatically.

The above drawbacks are significant and as a result most desiccant cooling systems incorporate some form of cooling coil. However, it is important to note that this cooling coil will be considerably less than that which would be incorporated into a conventional fresh air dehumidification system.

4 Solar application

Since desiccant cooling is a heat driven cycle, it would appear logical and synergistic that it might be powered by solar energy. However, the use of solar energy introduces constraints on the application of desiccant cooling. Assuming a ratio of solar collectors to building floor area of 1: 10, then the available heat (in northern Europe) to power the cooling cycle will be (conservatively) in the region of 25 to 50 W/m^2, depending on the climate, type and orientation of the solar collector. Consequently, the heat must be harnessed effectively. The desiccant cooling cycle is an open cycle, which rejects moist air at a high temperature, which is unsuitable for recirculation. Also the parasitic losses may be significant. The greater the air volume flow rate supplied to the room space, the greater the fan power required and the heat energy consumed. Therefore, if desiccant cooling is used in an all air application, the regeneration heat load is many times greater than the available solar energy. However, if the bulk of the sensible cooling within a space is carried out using a water based system such as a chilled ceiling, with the desiccant AHU dehumidifying and 'tempering' the incoming fresh air, then the air volumes handled will be much less and the 'solar energy' may make a significant contribution.

Theoretical work by Beggs and Warwicker has shown that desiccant cooling is best applied to installations in which the bulk of the sensible cooling is performed by a system such as a chilled ceiling [2]. In such an application the desiccant system treats only the incoming ventilation air. Because chilled ceilings are designed to have a dew point of approximately 17°C, it is possible to use low grade chilled water which can be produced using evaporative cooling towers. This avoids the need to install vapour compression refrigeration machinery,

5 The solar desiccant model

In order to investigate the potential for coupling a desiccant system to solar collectors in a European application, a solar desiccant computer model was developed at the University of Leeds. The model simulated the psychrometric and thermodynamic processes associated with desiccant cooling, using the following assumptions:

- The desiccant cooling system was employed solely to dehumidify the incoming fresh air supply, and to provide when required supplementary sensible cooling. It was assumed that the bulk of the sensible cooling would be performed by a separate water based system.

- The desiccant cooling system did not contain a cooling coil. The required degree of sensible cooling being achieved through the use of an evaporative cooler.
- The desiccant cooling system contained a solar heating coil located directly before the regeneration coil.
- The desiccant cooling system incorporated a 20% bypass on both solar heating and regeneration coils.
- Regeneration and supply air temperatures were specified, and the room condition was allowed to vary.

The solar desiccant cooling model considered only the primary and delivered energy consumption associated with the thermal aspects of the desiccant cooling cycle. The associated fan energy consumption was ignored.

6 Methodology

In the theoretical study, the system shown in Figure 3 was analysed in order to determine the running cost, primary energy consumption and CO, emissions attributable to a desiccant cooling system on a m^2 of floor area basis.

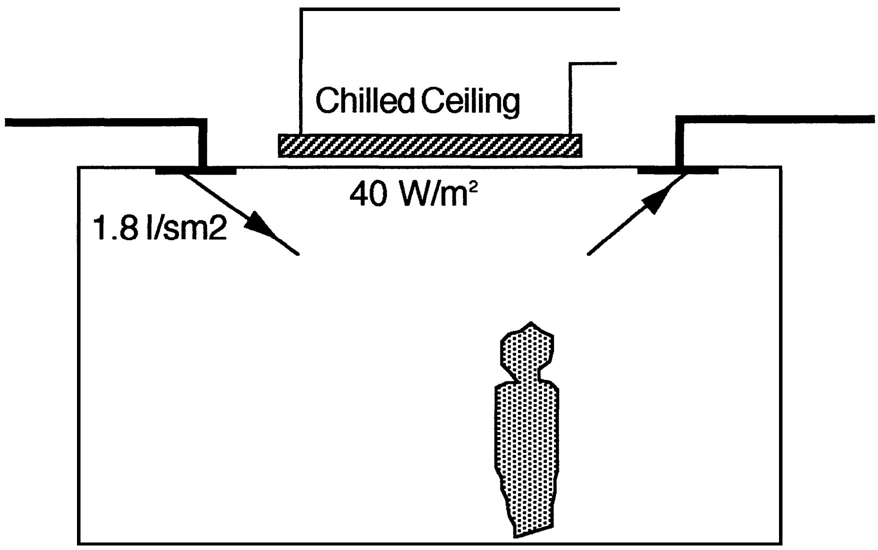

Figure 3: A chilled ceiling application in an office building where fresh air is introduced at high level

The system was analysed in cooling mode only, under the part-load conditions shown in Table 1. The study focused solely on the energy consumption of the desiccant fresh air system. In the study the energy consumption of the chilled ceiling was ignored, since this cannot be connected to a solar energy supply. The maximum sensible cooling output of the chilled ceiling was assumed to be 40 W/m^2. It was assumed in the study that under peak load conditions the desiccant cooling system would make-up the 10 W/m^2 short fall in sensible cooling. However, under part load the desiccant system would supply air to the space at room temperature. The psychrometric processes involved in the study are shown in Figure 4.

	Sensible Heat Gain (W/m2)	Latent Heat Gain (W/m2)	Outside Air Temp (0C)	Outside Air Percent. Sat (%)	Outside Air Moist.Cont. (g/kg)
Loading					
Peak	50	7	30	50	13.7
Mid	40	7	26	50	10.7
LOW	30	7	22	50	8.4

Table 1: Part-load data used in Parametric Study

Throughout the study it was assumed that the solar heating coil was connected to solar panels via insulated pipework, containing a glycol/water mixture having a specific heat capacity of 3.7 kJ/kgK. The glycollwater flow rate was assumed to be 0.0016kg/s per m^2 of floor area, which equated to a solar collector to floor area ratio of 1: 10. The glycollwater flow and return temperatures were assumed to be a constant 60.1°C and 53.9°C respectively, providing 36.7 W/m^2 of heat energy to the desiccant cooling system. In reality this value would vary considerably depending on time, solar insolation, orientation and collector type. However, the purpose of the study was to investigate the feasibility of using solar energy to drive a desiccant cooling installation, and so a constant relatively pessimistic value was chosen.

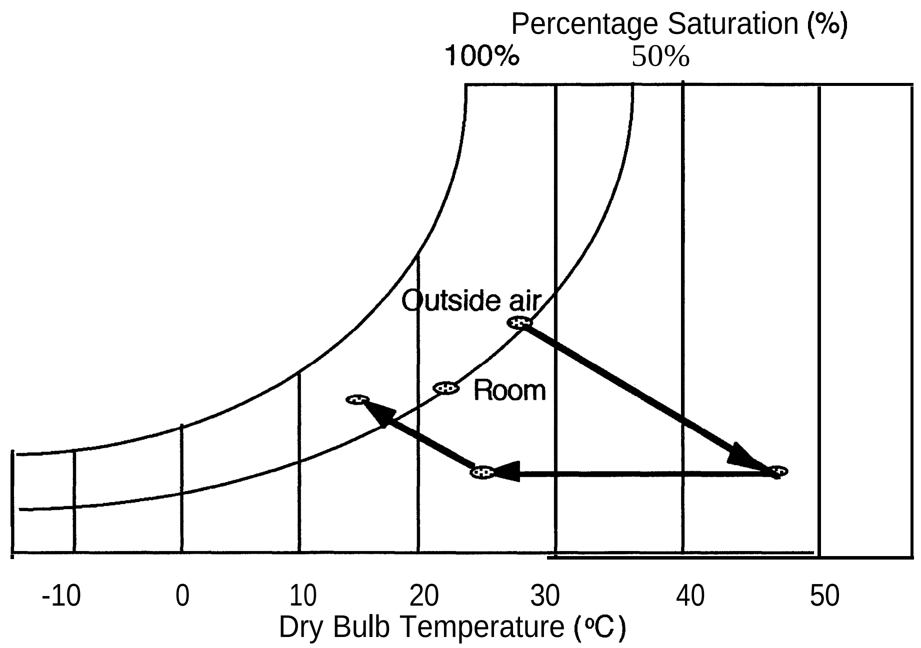

Figure 4: Psychrometric process (For clarity the return air cycle is omitted)

The operating data for the study is shown in Table 2. It should be noted that the degree of sensible cooling achieved by the desiccant cooling system is governed by the degree of dehumidification achieved by the desiccant wheel,-and that this in turn is governed by the regeneration air temperature. In short, the greater the regeneration air temperature, the lower the supply air temperature achievable to the room space. In order to determine the impact of varying the regeneration air temperature on the energy consumption of the cycle, the peak load condition simulation was carried out twice; once with a regeneration temperature of 55°C and a supply air temperature of 20.5°C, and once with a regeneration temperature of 75°C which enabled the supply air temperature to be reduced to 20°C. There was no benefit to be gained from raising the regeneration air temperature

- Section 7, and the remaining part-load simulations were undertaken using a regeneration air temperature of 55°C. The energy data applied in the study is shown in Table 3.

Loading	Supply Air Volume Flow Rate (l/sm 2)	Regen Air Temp. (°C)	Moisture Cont. Leaving Desic. Wheel (g/kg)	Ceiling Cooling output (W/m2)	Sensible Cooling From Desiccant Cooling System (W/m2)	Supply Air Condition Peak
Peak	1.8	55	10.2	40.0	10.0	20.5°C & 13.8 glkg
Peak	1.8	75	7.7	40.0	10.0	20.0°C & 12.2 glkg
Mid	1.8	55	7.3	40.0	0.0	22.0°C & 8.4 glkg
Low	1.8	55	5.1	30.0	0.0	22.0°C & 5.1 gtkg

Table 2: Operating data for the various loadings

Unit cost of gas	**1 SO p/kWh**
Unit cost of electricity	**5.00 p/kWh**
Efficiency of heating system	**70 %**
COP of DX/chilled water coil system	**2.5**
Electrical generation efficiency	**35 %**
CO, coefficient for gas consumed	**0.21 g/kWh**
CO, coefficient for electricity consumed	**0.68 kg/kWh**

Table 3: Cost and energy data used in analysis

7 Results

The results of the study are shown in Table 4.

System	Regen. Air Temp. (°C)	Supply Air Condition	Room Air Condition	Regen. coil Duty (W/m²)	Delivered gas (Wh/h/m²)	Cost per hour (p/h/m²)	CO_2 produced (kg/h/m²)
Non-solar (Peak)	55	20.5°C & 13.8 glkg	25.0°C & 15.2 glkg	30	43	0.07	0.009
Solar (Peak)	55	20.5°C & 13.8 g/kg	25.0°C & 15.2 g/kg	1	2	0.00	0.000
Non-solar (Peak)	75	20.0°C & 12.2 g/kg	24.5°C & 13.5 g/kg	54	77	0.12	0.016
Solar (Peak)	75	20.0°C & 12.2 glkg	24.5°C & 13.5 g/kg	25	35	0.05	0.007
Non-solar (Mid.)	55	22.0°C & 8.4 glkg	22.0°C & 9.7 glkg	38	54	0.08	0.011
Solar (Mid.)	55	22.0°C & 8.4 g/kg	22.0°C & 9.7 g/kg	9	12	0.02	0.003
Non-solar (Low)	55	22.0°C & 5.1 g/kg	22.0°C & 6.4 glkg	45	64	0.10	0.013
Solar (Low)	55	22.0°C & 5.1 g/kg	22.0°C & 6.4 glkg	16	22	0.03	0.005

Table 4: Analysis results (system incorporating evaporative cooler)

It can be seen from the results presented in Table 4 that coupling the desiccant cooling system to solar collectors produces significant savings in both running cost and CO, emissions. The greatest saving was achieved at peak load. This is because the return air leaves the thermal wheel at a higher temperature, and consequently, the solar heater is almost able to achieve an air temperature of 55°C without much help from the regeneration coil. However, despite the impressive energy savings achieved, based on these assumptions, the results indicate that operation of the system without a cooling coil is quite impracticable for most applications, since it results in high room air humidities. Indeed, for the installation shown in Figure 3 the results indicate that for much of the year condensation would occur on the surface of the chilled ceiling. However, this problem can be overcome by replacing the evaporative cooler by a small DX or chilled water cooling coil. If the study is repeated using a cooling coil instead of an evaporative cooler, then the results achieved are those shown in Table 5.

System	Regen. Air Temp. (°C)	Supply Air Condition	Room Air Condition	Regen. Duty (W/m²)	Delivered gas (Wh/h/m²)	Delivered electricity (Wh/h/m²)	Cost per hour (p/h/m²)	CO_2 produced (kg/h/m²)
Non-solar (Peak)	55	17.5°C & 10.2 g/kg	22.0°C & 11.5 g/kg	32.1	7.0	45.8	0.10	0.014
Solar (Peak)	55	17.5°C & 10.2 glkg	22.0°C & 11.5 glkg	2.5	7.0	3.6	0.04	0.006
Non-solar (Mid.)	55	22.0°C & 7.3 glkg	22.0°C & 8.6 glkg	38.9	0.4	55.6	0.09	0.012
Solar (Mid.)	55	22.0°C & 7.3 glkg	22.0°C & 8.6 g/kg	1.1	0.4	1.6	0.00	0.001
Non-solar (Low)	55	22.0°C & 5.1 g/kg	22.0°C & 6.4 glkg	45.0	0.0	64.2	0.10	0.013
Solar (Low)	55	22.0°C & 5.1 glkg	22.0°C & 6.4 glkg	16.0	0.0	22.9	0.03	0.005

Table 5: Analysis results (system incorporating cooling coil)

Table 5 shows that the inclusion of a refrigerated cooling coil increases CO, production under peak-load conditions, however for most of the year it will be inoperative and thus the overall increase in CO, would be minimal. It should also be noted that despite the removal of the supply air evaporative cooler, the solar collectors are still able to significantly reduce the overall energy consumption, and CO, emissions of the system.

The results in Table 5 indicate that for most of the operating year the conditions achieved in the room space would be acceptable. However, the peak load results suggest that condensation might still be a problem if a regeneration air temperature of 55°C is used. Consequently, under peak load conditions it would be advisable to increase the regeneration air temperature to say 75°C which would achieve an acceptable room air condition of 22°C and 9.1g/kg moisture content. If the operating conditions of the solar panel are optimistic then it is likely that these regeneration temperatures could be achieved during peak demand.

8 Conclusions

The energy study reported in this paper represents an initial study to determine feasibility of coupling solar collectors to a desiccant cooling system in an northern European application. To this end the study has been successful, since it has demonstrated that the inclusion of a solar heater into the desiccant cooling cycle can result in large energy savings. Indeed, under the mid and low load scenarios the thermal energy costs are negligible.

The main conclusions to be derived from the energy study are as follows:

(i) The inclusion of a solar heater into the desiccant cooling cycle can lead to significant savings in primary energy consumption and associated CO, emissions.

(ii) Due to desiccant cooling being an open cycle, solar energy can only be effectively used in applications where the supply air volume flow rate is small. This effectively limits its application to installations where the bulk of the sensible cooling system is undertaken using a water based system.

(iii) The regeneration air temperature should be kept as low as is practically possible, in order to minimise fossil fuel energy input.

(iv) There is little or no benefit to be derived from using an evaporative cooler on the supply air side. The inclusion of such a device can result in increased energy consumption and unacceptably high air humidities in the room space. It is preferable to include a small refrigerated cooling coil, which is only used under conditions of peak load.

The study is at an exploratory stage and further work will investigate the consequences of varying supply volumes and regeneration temperatures. Solar data from a sample site will be used to provide realistic profiles of water supply temperature.

Acknowledgements

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References

1. Busweiler U.(1993) Air conditioning with a combination of radiant cooling, displacement ventilation, and desiccant cooling, *ASHRAE Transactions*, pp. 503-10
2. Beggs C. B., and War-wicker B. (1998) Desiccant cooling: Parametric Energy Study *Building Services Research and Technology*, Vol. 19, Number 2.
3. Smith J.T., and Webb B.C. (1995) A comparison of the CO, emission rates of gas-fired and electrically driven chiller/heater machines under dynamic loading. *Proceedings of the CIBSE National Conference, Eastbourne*, pp. 151-9
4. Munters Ltd. (undated) *MCC - Series Cooling Cassette*

Visualisation of 3-D city model on the Internet

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Abstract
In conventional GIS (Geographical Information System) technology and applications, the third dimension in reality is either ignored or treated as an attribute. Based on this methodology, only terrain surface can be incorporated and managed. However, urban planning and environment management demand the incorporation of, and interaction with man-made objects on top of the terrain, such as buildings in a GIS environment. The interaction and the analysis afterwards can only be best performed through effective 3 -D visualisation.

This article applies advanced Internet-based 3 -D visualisation technologies in visualising 3-D city model. In order to reach an effective visualisation, buildings should first be modelled in geometry, topology and appearance. This is done by using VRML, an advanced 3-D graphics standard for Internet-based visualisation and virtual reality. Textures and background images are also added to reach a photo-realistic effect. Because of the platform independence of VRML standard, any Web browser supporting VRML can be used to render the created world through the Internet.

In this article, a brief conceptual introduction to the 3-D city model is made, followed by an overview of visualisation technologies, where VR on the Internet and its development tool VRML are addressed. Methodology for modelling buildings with VRML in termes of geometry, topology and appearance are described with detailed examples. A virtual city environment for the campus of University College Gavle, Sweden is created and can be manipulated through the Internet. Further development towards an Internet-based desktop VR environment for virtual city is prospected.
Keywords: 3-D city model, GIS, IT, visualisation

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1. Introduction

Geographical Information System (GIS) is nowadays widely applied in urban planning and environmental management, and is becoming essential in many quantitative analyses in these areas [1][5][6]. However, conventional GIS technique uses the 2-D map as a basis for managing 3-D geographical data and planning decision. In this methodology, the third dimension is either ignored or treated as an attribute. Though this is sufficient for describing physical terrain surface, man-made objects on top of the terrain in urban environment, such as buildings, traffic networks, i.e., a 3-D city, can not be managed. Advances in 3-D computer graphics and visualisation technologies are making it possible to model, manage and visualise the reality in a true 3-D mode.

The emerging of Internet technology and its spreading application are making the distribution, query, display and processing of geographical data possible through and on the Internet. The demand on visualising geographical data on the Internet environment is becoming higher. Although the geographical data can be visualised through the Internet via using different image formats (in 2-D), the interaction with the data and the stereoscopic effect are not possible without using advanced 3-D graphical tools running on the Internet.

This article applies advanced Internet-based 3-D visualisation technologies in visualising 3-D city model. A virtual city environment for the campus of University College Gävle, Sweden is created and can be manipulated through the Internet. The remainder of this article is organised as follows. Section 2 gives a brief conceptual introduction to the 3-D city model, followed by an overview of visualisation technologies in section 3, where VR (Virtual Reality) on the Internet and its development tool VRML (Virtual Reality Modelling Language) are addressed. Section 4 describes the methodology for modelling buildings with VRML in termes of geometry, topology and appearance. Sample results together with discussions are given in section 5, before this article is summarised in section 6.

2. 3-D city model

3-D city model is a three-dimensional digital description of an urban environment. Instead of conventional phenomena in physical geography depicted on topographical maps, such as terrain, vegetation area, water bodies, a 3-D city model is mainly composed of man-made objects, especially buildings, culture constructions, and traffic networks.

In order to establish a 3-D city model and manipulate it effectively, three fundamental issues are involved, namely constructing the models or modelling, managing the model based on database technologies so that spatial query is possible, and visualising the model [3][5][6]. 0nce the modelling process is completed, visualisation will be served as an interface for effective spatial query and analysis. This article will mainly discuss the modelling and visualisation issues.

A complete modelling should include geometric, topologic and thematic issues of the 3-D city. Geometry determines the size, shape and local or global location of any object in the 3-D city. The relative relationship among objects is described by topologic modelling procedure. Thematic modelling assigns the geographic objects with attributes. Besides, for visualisation purpose, objects in a 3-D city model will be given colour, texture, image etc. to model their appearance.

3-D city model is used in diverse areas. Urban planning needs 3-D city model for city development. Telecommunication industry is in need of 3-D city model to best locate mobile transmission stations in urban environment. A realistic virtual 3-D city can help architects with designing new buildings in an interactive mode. Tourists may experience the virtual 3-D scene before the on-site visiting.

3. Visualisation technologies

As a subject of computer graphics, visualisation has dynamically been changing its technologies in the past decades. 3-D graphical display and processing capabilities are now as a standard function in desktop environment, such as on workstation and high-end PCs. Industrial graphic libraries, like Open GL and Open Inventor, have functions to perform complex graphic processing tasks, such as shading and hidden element removal, which would otherwise be done only with lengthy codes.

Recent advances in computer graphics lead to a demanding research and application subject - virtual reality (VR) [4], which presents a compelling concept: a natural and effective interaction between user and computer through visualisation. The display of a 3-D city model, integrated with possible interaction, is called virtual city. Through an effective interface one can walk-through the city, go shopping and even chat with other people who are visiting the virtual city at the same time [5]. Thematic information about the current visiting place is available by clicking the mouse button on any interesting area. Once the 3-D city model is geo-referenced, it will act as a 3-D map with accuracy and realism, shared and connected locally and globally.

The integration of Internet and visualisation technology makes it possible to render the 3-D city model over the Internet. For this purpose, the VRML is developed, which is now acknowledged as an industrial standard for VR development over the Internet. The created VRML file can then be rendered via a browser, such as Cosmo Player, to get three dimensional effect and perform man-machine interaction. The current (1997.12) version VRML 2.0, released in August 1996 and revised as VRML97 in April, 1997, is capable of handling animation and integrating multimedia, such as sound, movie and image [2].

4. Modelling buildings with VRML

4.1 Introduction to VRML

VRML uses a hierarchical scene graph to describe the 3-D world [2]. Entities in the scene graph are called nodes. Nodes store their data in fields. Nodes can contain other nodes and may be contained by more than one nodes. By organising the nodes and specifying their values, one can model the geometry and topology of the geographical data. Illumination and appearance of the world can be defined by corresponding nodes as well. In addition , image textures can be transformed and added on top of the geographical surface, such as terrain and urban area. Another distinct characteristic of VRML is LOD (Levels Of Detail).The world is first defined in different versions of detail. VRML browser will automatically choose and display the appropriate version of the world based on the distance from the viewer.

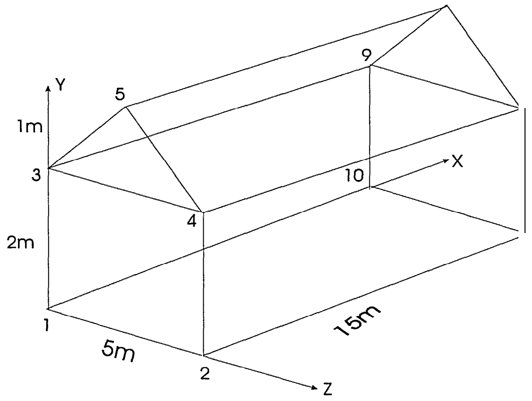
One can interact with the view so that any part of the world, as long as it is modelled by VRML, can be examined in any path at any orientation and at any scale. Textures can be pasted on the surface of the world as to obtain a photo-realistic result. In such a way one can experience the immersion into the geographical environment through navigating the virtual reality.

4.2 Modelling buildings

Modelling is to establish a description of the world based on a grammar which is interpretable for a visualisation system. It is the first step in visualisation. A comprehensive description should minimum include the geometry, topology and appearance of the world, illumination condition and viewer attitude.

Buildings should be modelled in geometry as well as in topology. In addition to giving the coordinates of vertices composing a building, their connectivity, namely how the faces are formed by which vertices, should also be specified. Following VRML codes are used to describe the building beside

```
Shape {
 geometry IndexedFaceSet {
   coord Coordinate {
    point [ 0 0 0
      0 0 0, 0 0 5, 0 2 0, 0 2 5, 0 3 2.5,
      15 0 5, 15 2 5, 15 3 2.5, 15 2 0, 15 0 0, ]
  }
   CoordIndex [
   1,2,4,3,-1,4,5,3,-1,2,6,7,4,-1,6,10,9,7,-1,7,9,8,-1
   1,3,9,10,-1,3,5,8,9,-1,5,7,8,5,-1,1,10,6,2,-1]
 }
}
```



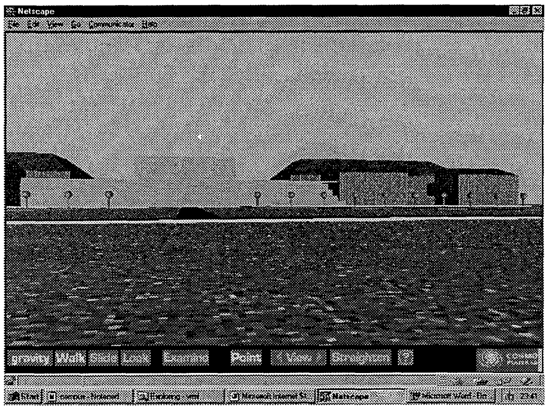
Modeling a building

4.3 Modelling the appearance

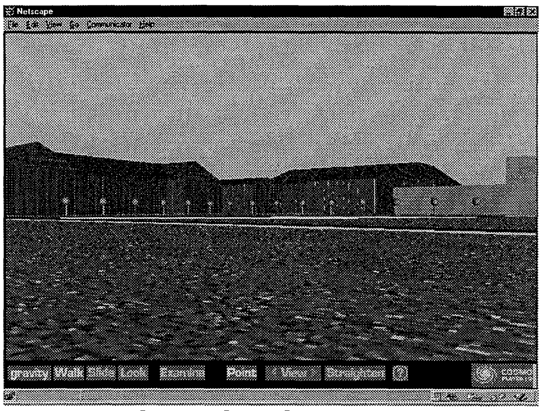
The appearance will affect the final effect of visualisation. There are various optional parameters to choose in VRML, such as the location, direction and type of illumination, reflection properties of the world, types of colour and texture, scale etc. To simulate the reality and the circumstances one views the object, directional light from upper-left (north-west) is chosen. The surface of the world is often chosen as having diffuse reflection. Initial attitude of viewing location is also carefully determined so that a proper initial view can be obtained.

5. Sample results and discussion

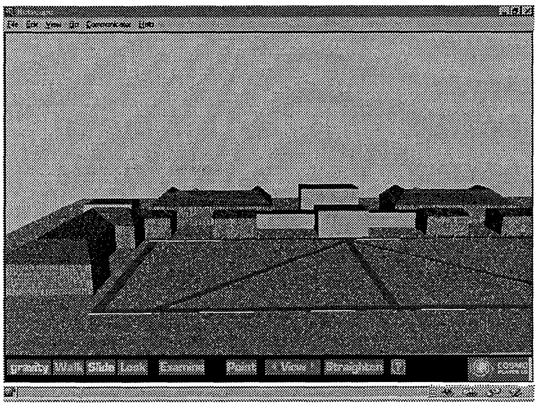
A VRML world for the campus of University College Gävle, Sweden is created. It includes buildings, trees and grasslands. The file is composed by text editor based on the building blueprint and aerial photographs. Sample results are given in following figures.



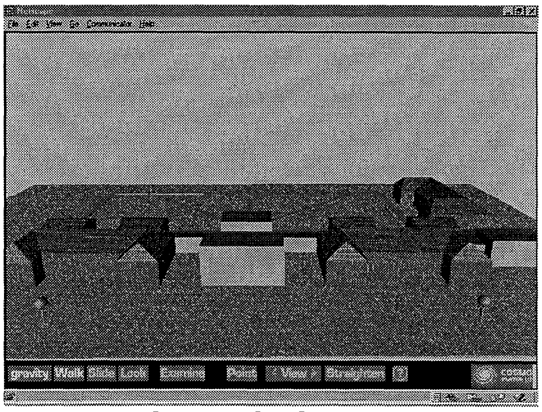
a. Back-left view



b. Back-right view



c. Back bird-view



d. Front bird-view

Geometric primitives, colours and textures are used in the creation of the virtual world. Cosmo Player and World View are chosen as browsers. By clicking interesting location on the view one can examine that spot at a larger scale, animate the scene via panoramic view and fly through the view.

There are optional parameters in the VRML for a programmer to choose proper appearance such as colour, intensity, illumination, initial view etc., however, they are hardly to determine with minor efforts. Creative author tool for this purpose is thus recommended to obtain optimal visualisation result.

6. Summary

3-D city model can be applied in, among others, urban planning, tele-communication, tourism, transportation, architecture and environment management. The integration of visualisation technologies and Internet enables the Internet-based visualisation. VRML offers powerful functions to model the 3-D city, which can then be rendered through a browser over the Internet. As for the future work, a VR system for integrating modelling, rendering and querying the 3-D city is expected to be developed in a desktop environment.

References

1. 3-D city models, Minutes for the workshop of 3-D city models, Institute for Photogrammetry, Bonn University, 1996.
2. Carey, R and Bell, G. (1997). The annotated VRML97 reference manual. http://www.best.com/~rikk/Book/book.html
3. Kofler, M., Rehatschek, H., Gruber, M. (1996). A database for a 3-D GIS for urban environments supporting photorealistic visualisation, International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, Part B2, pp. 198-202.
4. Rosenblum, L.J. and Cross, R.A. (1997). The challenge of Virtual Reality, in Visualisation and Modelling, edited by R.Eamshaw, J.Vince,H. Jones. Academic Press, 1997, pp.325-339.
5. Smith,A., Dodge, M. and Doyle, S. (1997). Urban science, GIS Europe, October, pp.26929.
6. Tempfli, K. and Pilouk, M. (1996). Practical photogrammetry for 3D-GIS. International Archives of Photogrammetry and Remote Sensing, Vol. XXXI, Part B4, pp.859-867.

Functional analysis as a method to design new building components

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Abstract
The paper presents a method to develop a functional analysis as a tool for designing new building components well balanced with respect to the different aspects of the technological quality: performances of a component at the beginning of service life, during service life and maintainability.

The analysis begins from a set of hypothesis of functional models which foresees different organisations of the distributions of functions through the structure of the component. These are the functions which the component must be able to develop in order to assure the technological performance goals, i.e. the functions strictly linked with the performances.

This analysis goes on through a set of actual models; every actual model comes from one of the previously set out functional models and foresees different choices of functional elements of the-component; every functional element will have defined values of the functional characteristics, i.e. the characteristics linked to performances, that must be held by the materials chosen to form the component (see paper "Methodology and experimental programme to evaluate building components and service life", Politecnico di Milano, DISET).

In this way it is possible to achieve the goals of a design of innovative building components within a policy of sustainable construction approach, which implies a balanced use of materials and natural resources without compromising the ability of future generations to satisfy their needs.
Keywords: Building components, durability, functional analysis, maintainability, performances, service life, sustainable construction.

1 Introduction

The paper's subject takes place in the general theme of the Symposium "Material and technologies for sustainable construction" and, in particular, in the main theme "Performance, durability and service life".

The problem's solution of the sustainable development in building sector passes through the individuation of the priorities in the choice of the materials to be used in the design and the production of building components. The choice of these materials must take into account their compatibility with the global equilibrium of use of natural resources. Therefore only the materials of which this compatibility is recognised should be taken into account for an environmental conscious building process.That is to say materials which minimise the intrinsic energetic waste of the involved raw materials, the energetic waste due to the transformation into building materials, the waste implied by an eventual recycling to reduce the environmental impact.

Within some years at DISET, Politecnico di Milano, it has been developped researches, coordinated by prof. P.N. Maggi, about setting up of evaluation methods for the three components of building components technological quality: zero time quality (characteristic quality) quality during service life (durability) and maintenance quality (maintainability).

This paper, related with other papers titled: "Methodology and experimental programme to evaluate building components service life" and "Experimental programme to evaluate building components service life: an application", reports about the functional analysis (see Figure 1 and Figure 2), as a building components design method; it allows to operate a choice in the following terms:

- at the beginning the materials selection and/or building components is based on a service life optimisation. In this design phase are calculated the real dimensions which avoid materials over-usage. The innovation which this paper, related with the two others, is proposing is the goal of a full rationalisation of the entire process, from the conception and design until the service life and the maintenance;
- in a second step will be operated, if necessary, a further reduction of the choices, considering only those materials recognised as compatible with a sustainable construction.

2 Building component functional analysis method

The functional analysis method allows to define during conception and design phase a building component belonging to a given class. In this way it is possible to define also its performances parameters values (characteristic quality, durability, maintenance quality and executive quality).

In the conception phase the design process can be controlled following the iter here indicated.

Given, for a specific list of building components classes, a fundamental functions package, individuated as those functions which generate the building components technological requirements, can be built the working model of the building component.

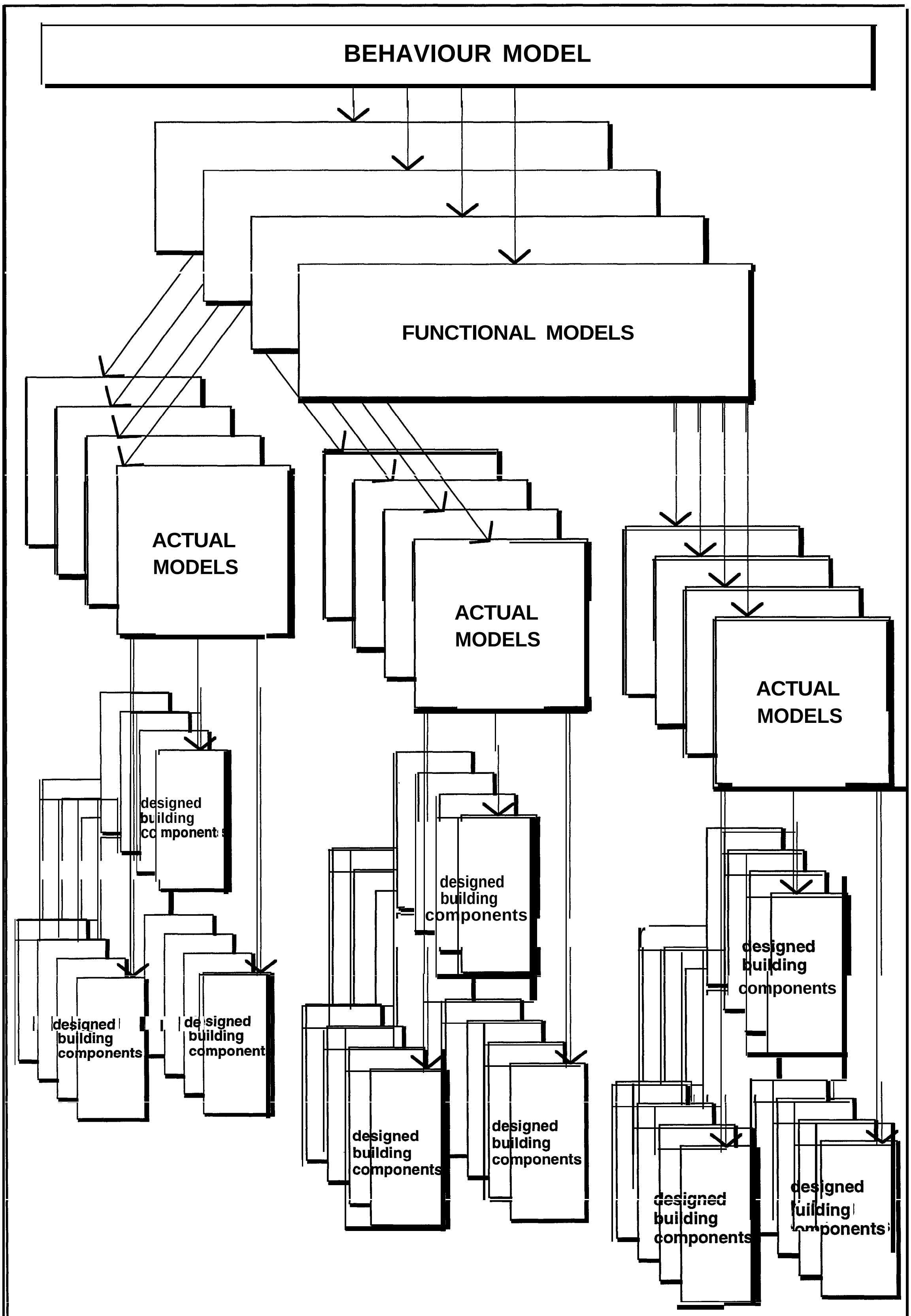

Figure 1: Steps in building components designing

BEHAVIOUR MODEL

technologicals requirements
- interstitial condensation control
- superficial condensation control
- thermal inertia control in hot season
- thermal inertia control in cold season
- acoustic insulation
- thermal insulation
- suspended loads mechanical resistance
- watertight

FUNDAMENTAL FUNCTIONS

F1- to control interstitial condensation
F1- to control superficial condensation
F3- to control thermal inertia in hot season
F4- to control thermal inertia in cold season
F5- to control acoustic insulation
F6- to control thermal insulation
F7- to control suspended loads mechanical resistance
F8- to control watertight

WORKING MODEL

FUNCTIONAL MODEL

E	I	II	III	IV	V	I
	f h.1	fh.1	fc.1			
		fc'.2	fc.2	fc'.2	ff.2	
		fc'.3	fc.3	fd.3		
		fc'.4	fc.4	fd'.4		
	fp.5	fm.5	fo.5	fm'.5		
		fc'.6	fc.6	fc'.6		
				fr.7	fr.7	
	ft'.8	ft'.8				

ACTUAL MODEL

E	①	②	③	Ⓢ	④	⑤	⑥	⑦	I
F 1	fh.1	fh.1	fh.1		fc.1				
F 2			fc'.2		fc.2	fc'.2	ff.2		
F 3			fc'.3		fc.3	fd.3			
F 4			fc'.4		fc.4	fd'.4			
F 5	fp.5	fp.5	fm.5		fc.5	fm'.5			
F 6			fc'.6		fc.6	fc'.6			
F 7						fr.7	fr.7		
F 8	ft'.8	ft'.8	ft'.8						

BUILDING COMPONENT

	FUNCTIONAL ELEMENTS	THICKNESS (cm)
1	plastic covering with continuous application with an acrylic base	0.2
2	rustic plaster	1.3
3	semi-hollow brick and laying mortar	12.0
A	glue with a syntetic-cement base	0,5
4	resin panel of fibregass	4.0
5	perforated bricks and laying mortar	8.0
6	skim-coat	1.5
7	wash-painting with acrylic base	...
	total thickness	27,5

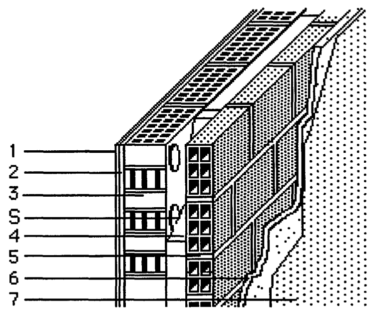

Figure 2: Building component design process

This model (functional model + actual model) individuates where are applied the specific functions which characterise the building component.

The fundamental functions of the functional model come from the technological requirements of the specific building components class and each of them consists in several analytical functions (see figure 3). The building component technological requirements compose the building component behaviour model.

To be noted that one behaviour model can generate several functional models which even if alternatives one to each other, are all coherent with the generator model.

The successive phase consists in an elaboration of alternatives of actual models all coherent with a given functional model.

For the elaboration of the alternatives of the actual models, starting from the spots of the corresponding functional model, these spots are transformed in a functional elements structure.

To each functional element are assigned the analytical functions groups to be accomplished and then the corresponding functional characteristics and the value ranges which these characteristics must show.

To be noted that for each functional model can be individuated several actual models, but coherent.

The successive phase consists in the design of a building component which for each actual model, previously identified, implies, for each functional element of the model, the choice of the materials which must meet the functional characteristics coherent with those admitted by the corresponding actual model.

To be noted that each actual model can generate several designs of building component (see Figure 1).

At this point of the functional analysis, the methodology allows to optimise the choice of the design of the building component either for durability or for maintainability.

For the durability optimisation will be chosen those materials which show the smaller functional obsolescence of their functional characteristics.

As far as the maintainability optimisation is concerned will be chosen those materials and the configuration of the building component which make easier the maintenance interventions, i.e. which maximise the value of the availability to maintainability and then minimise the average time of repairing.

FUNDAMENTAL FUNCTIONS, ANALYTICAL FUNCTIONS FOR EXTERNAL NON-BEARING WALLS	F1 TO CONTROL INTERSTITIAL CONDENSATION	F2 TOCONTROL SUPERFICIAL CONDENSATION	F3 TOCONTROL THERMAL INERTIA IN HOT SEASON	F4 TO CONTROL THERMAL INERTIA IN COLD SEASON	F5 TO CONTROL ACOUSTIC INSULATION	F6 TO CONTROL THERMAL INSULATION	F7 TO RESIST TO HANGING LOADS	F8 TO CONTROL WATER INFILTRATION
fa to resist to radiative heat flows		●	●	●		●		
fb 0 resist to convective heat flows		●	●	●		●		
fc to resist to conductive heat flows	●	●	●	●		●		
fd to provide heat storage			●	●				
fe to foster convective heat flows			●					
ff to foster water re-evaporation	●	●						●
fg to resist to water vapour permeation	●							
fh to provide water vapour permeation	●							
fi to provide constant resistance to water vapour permeation	●							
fl to provide constant resistance to heat transmission	●							
fm to hinder by mass the transmission of sound waves					●			
fn to interrupt the transmission of sound wavesin solids					●			
provide r-elastic darnpening in solid mean					●			
to provide air tightness					●			
fq to provide acoustic absorption					●			
fr to provide compressive strength.							●	
fs to provide bending strength							●	
ft to provide resistancee to water flow								●
fu provide opposition to capillary water permeation								●

Figure 3: Division of fundamental functions into analytical functions for external non-bearing walls

3 Conclusions

Applying the functional analysis methodology to the design phase of a building component it is possible, through successive approximations, to rationalise and optimise the process, obtaining a correct dimensioning of the single materials responding to the individuated functions, and which compose the building component functional elements.

The design development following the exposed criteria, if from one side allows to obtain a saving in terms of material resources, from the other side can become an instrument finalised to the design of innovative products in the respect of the sustainable construction.

It is actually possible, following the individuated design process, to orient the choice to innovative products already present on the market or to promote the conception and design of other ones, compatible with the functional models and with the durability and maintainability objectives established.

The conception and design of innovative products above prefigured, compatible with the global equilibrium of use of natural resources, can be operated by organisations coherent accordingly to ISO14001.

4 References

1. Rejna, M., Gottfried, A., Maggi, P.N. Ravetta, F.(1996) *Method for reliability evaluation of building: application on a set of component,* CIB, ASTM, ISO, RILEM International Symposium "Application of the performance concept in building", Tel Aviv, Israel.
2. Diset - Politecnico di Milano - Maggi, P.N., Daniotti, B., Gottfried, A., Morra, L., *(1994) "Control of project pathologies of building components: methodology for the evaluation of the reliability" CIB,* ICITE, Varenna, Italy.
3. MURST, Diset - Politecnico di Milano (1996) *"Criteri di valutazione della propensione di durata in funzione degli andamenti qualitativi di variazione delle caratteristiche funzionali delle soluzioni tecniche",* Torino, Italy.

Environmental evaluation of external clay brick masonry

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Abstract
The paper presents part of an ongoing research programme into the Environmental Impact of Buildings. It concentrates on environmental impact of external clay brick masonry, which is the most widespread technical solution in Italy. The aim of the study is to help designers in taking decisions about low impact building techniques. Eighteen clay brick masonry systems having the same thermal transmittance value have been studied. Each system has a different environmental profile and an attempt was made to evaluate them, according to the following parameters: resource quality, embodied energy, recycling possibility, environmental effects.
Key words: clay brick masonry, comparison among technical alternatives, design, environmental profiles, low impact building techniques, sustainable construction.

1 Introduction

The research deals with the problem of environmental quality of certain technical design solutions for external walls; brick technology has been selected as the prime focus of the study because it is the most widespread technical design solution used for buildings in Italy. The research was carried out through six phases:

1. Definition of technological solutions directory
2. Definition of functional unit
3. Drawing up of descriptive cards for the technical solutions and calculation of the included materials
4. Impacts inventories for the main materials: bricks and insulating materials
5. Implementation of an electronic sheet for the environmental effects calculation
6. Drawing up of comparative environmental profiles for the main solutions.

Each of these phases is described in detail below.

1.1 Definition of a technical solutions directory

Brick walls may be built using different solutions that vary from one another according to the kind of brick used, the kind of insulating material (fireboard, expanded materials - organic or inorganic), according to its position in the wall (on the outside face, in the cavity, on the inside face), as well as the different succession of elements in the wall and the possible presence of cavities. In this study the following functional models have been considered:

Functional Model	Technical Solution	Type of wall
Externally insulated wall	Hydraulic plaster on insulation	Single layer wall
Ventilated wall	Ventilated wall	Single layer wall
Insulated cavity wall	Double layer wall	Double layer wall
Internally insulated wall	Thin partitions	Single layer wall

Table 1. Functional models and technical solution analysed in this study

Altogether, 18 technical design solutions have been selected and each of them has been considered with seven different insulating material; such an inventory of 126 alternative technical solutions was analysed in this project.

1.2 Definition of a functional unit

In order to make a comparison between the various design solutions, the functional unit was fixed as follows:

- surface of external wall: 1 m^2;
- thickness and layers: to obtain, for each solution, a fixed thermal transmittance value: 0.375 W/m^2K;
- durability: 30 years.

To obtain the required thermal transmittance value thicknesses of different design solutions vary therefore in relation to the kind of bricks and insulating materials chosen

1.3 Description of design solutions and calculation material characteristics

Description of the chosen technical solutions have been worked out as shown for example in Figure 2. Each solution has been described in a format that takes into consideration the material properties, number of layers, their position, presence of an air gap layer etc.

which considers its materials, layers and thicknesses. Figure 2 shows an example of card.

1.4 Inventory of impacts for the most important materials: bricks and insulating materials

Information on bricks have been taken from an environmental analysis developed by ANDIL (Associazione Nazionale degli Industriali del Laterizio, Italy)[2]; information on mineral and natural insulating materials have been drawn from a bibliography on the subject; information on polymeric materials have been drawn from APME (Association of Plastic Manufacturers in Europe). The data were referenced to **1** kg of finished product considering its whole life cycle.

1.5 Calculation of environmental effects; implementation using an electronic 'sheet'

An electronic sheet was developed in order to collect inventories' data and to transform them into the specific contributions to environmental effects of each functional unit. The environmental effects that were considered are the ones given according to the CML methodology[4]: i.e., greenhouse effect, ozone depletion, human toxicity, photochemical oxidant formation, acidification and nutrification. Moreover, the sheet calculates the global energy consumption of a given solution as well as the quality of the resource.

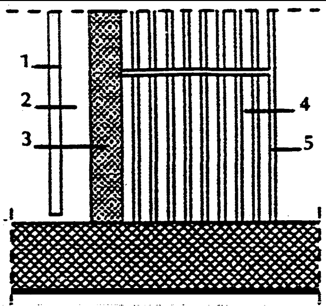
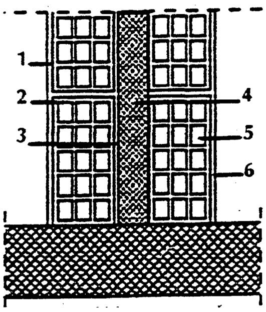
VENTILATED WALL	
	**Solution's description** It's a single layer wall made with perforated bricks covered by an hydraulic plaster, the insulating material is glued on the external surface and ventilation is created through an air-gap layer.
Type of brick	
Perforated bricks Dimensions (mm) 250x180x160 Apparent density (kg/m^3) 820 Hollow (% and Type) 43 V Thermal resistence (m^{2}K/W) 0.43	
TECHNICAL ALTERNATIVES	
Type of insulating material	**Layers**
Rock-wool panels Thickness (mm) 70 Apparent density (kg/m^3) 70 Calculation conductivity (W/mK) 0.038	1. External plaster in lime and cement mortar 30 mm 2. Faintly ventilated air-gap 40 mm 3. Insulating material 70 mm 4. Masonry in perforated bricks 250 mm 5. Internal plaster in lime and cement mortar 15 mm
Glass wool panels Thickness (mm) 70 Apparent density (kg/m^3) 70 Calculation conductivity (W/mK) 0.038	1. External plaster in lime and cement mortar 30 mm 2. Faintly ventilated air-gap 40 mm 3. Insulating material 70 mm 4. Masonry in perforated bricks 250 mm 5. Internal plaster in lime and cement mortar 15 mm
Cellular glass panels Thickness (mm) 70 Apparent density (kg/m^3) 70 Calculation conductivity (W/mK) 0.038	1. External plaster in lime and cement mortar 30 mm 2. Faintly ventilated air-gap 40 mm 3. Insulating material 80 mm 4. Masonry in perforated bricks 250 mm 5. Internal plaster in lime and cement mortar 15 mm
Expanded polystyrene syntered panels Thickness (mm) 70 Apparent density (kg/m^3) 70 Calculation conductivity (W/mK) 0.038	1. External plaster in lime and cement mortar 30 mm 2. Faintly ventilated air-gap 40 mm 3. Insulating material 80 mm 4. Masonry in perforated bricks 250 mm 5. Internal plaster in lime and cement mortar 15 mm
Extruded polystyrene panels Thickness (nun) 70 Apparent density (kg/m^3) 70 Calculation conductivity (W/mK) 0.038	1. External plaster in lime and cement mortar 30 mm 2. Faintly ventilated air-gap 40 mm 3. Insulating material 60 mm 4. Masonry in perforated bricks 250 mm 5. Internal plaster in lime and cement mortar 15 mm

Figure **1**. Description of insulated cavity wall

In particular, the sheet describes the technical solution and it includes four sections: the first section collects data to calculate emission level; the second section transforms this data into environmental effects; the third section collects data related to energy consumption; the fourth section transforms the qualitative parameters (resources' quality and ricyclability) into impacts scores.
Figures 2 and **3** illustrate the sheet of one particular solution: i.e. a cavity wall insulated with cork.

INSULATED CAVITY WALL: DOUBLE LAYER 'WALL



Layers

1. External plaster in lime and cement mortar 15 mm
2. Masonry in hollow bricks 120 mm
3. Plaster in lime and cement mortar 15 mm
4. Insulating material 80 mm
5. Masonry in hollow bricks 120 mm
6. Internal plaster in lime and cement mortar 15 mm

SECTION 1: DATA FOR EMISSIONS' CALCULATION

CO_2	Specific weight (kg/m^3)	Volume (m^3)	Weight (kg)	Emission (g/kg)	Emission, (g)
Hollow bricks	600	0.240	144.000	36.000	5184.000
Plaster	1500	0.045	67.500	0.190	1 2 1
TOTAL					5196.825

SO_2	Specific weight (kg/m^3)	Volume (m^3)	Weight (kg)	Emission (g/kg)	Emission (g)
Hollow bricks	600	0.240	144.000	0.150	21.600
TOTAL					21.600

Fluorine	Specific weight (kg/m^3)	**Volume** (m^3)	Weight (kg)	Emission (g/kg)	Emission (g)
Hollow bricks	600	0.240	144.000	0.004	5.760
TOTAL					5.760

SECTION 2: EMISSIONS' CALCULATION

Greenhouse effect (kg of CO_2)

Emitted substances	Quantity (g)	Classification factor	Contribution to the environmental effect
CO_2	5196.825	1	5 196.825
TOTAL			5196.825

Acidification

Emitted substances	Quantity (g)	Classification factor	Contribution to the environmental effect
SO_2	21.600	1	21.600
TOTAL			21.600

Human toxicity (kg of contained body weight to the accettable maximum daily limit)

Emitted substances	**Quantity** (g)	Classification factor	Contribution to the environmental effect
SO_2	21.600	1.2	25.920
Fluorine	0.576	0.48	0.277
TOTAL			26.197

Figure 2. Electronic sheet for the calculation of the contribution to environmental effects of the Insulated Cavity Wall

SECTION 3: DATA FOR ENERGY CONSUMPTION'S CALCULATION

	Specific weight (kg/m^3)	Volume (m^3)	Weight (kg)	Energy consumption (MJ/kg)	Energy consumption (MJ)
Hollow bricks	600	0.240	144.000	2.890	416.160
Expanded cork	90	0.080	7.200	17.000	122.400
Plaster	1500	0,045	67.500	6.000	405.000
TOTAL					**943.560**

SECTION 4: QUALITATIVES SCORES

Resources' quality	Score		Components
Recycled	0		
Renewable	1	X	Expanded cork
Non renewable, but not scarce	2	X	Bricks
Non renewable	2		
Exausting	3		
TOTAL .		3	

Recyclability	Score		Components
Recycle within the productive cycle in the same product	0	2 x	Bricks Expanded cork
Recycle post-use in the same product	0	X	Expanded cork
Recycle ante-use or post-use into another product	0	2 x	Bricks Expanded cork
Incineration with energy recovery	1	X	Expanded cork
Incineration	2		
Landfill	3	X	Briks
TOTAL		4	

Figure 3. Electronic sheet for the calculation of the contribution to environmental effects of the Insulated Cavity Wall (continued from previous page)

1.6 Comparative environmental profiles for the most significant technical solutions

In order to compare the different technical solutions, the contributions to environmental effects were transformed into graphic profiles, as show Figures 4a to 4f below.

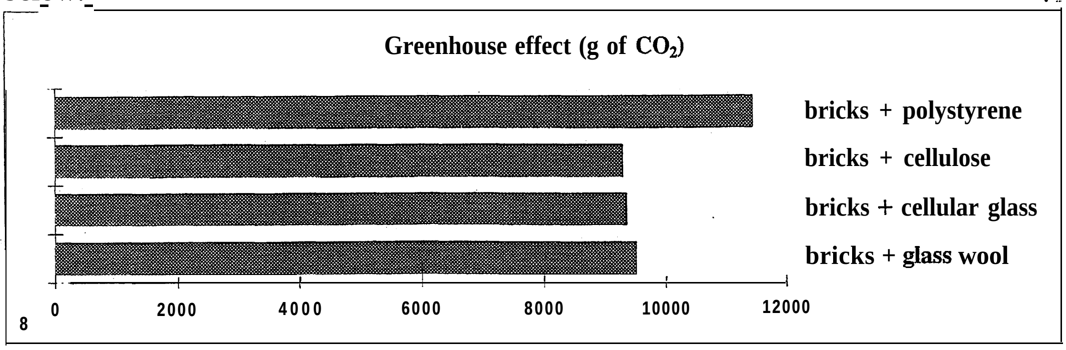


Figure 4a. Comparison among environmental profiles of insulated cavity walls having different insulating materials

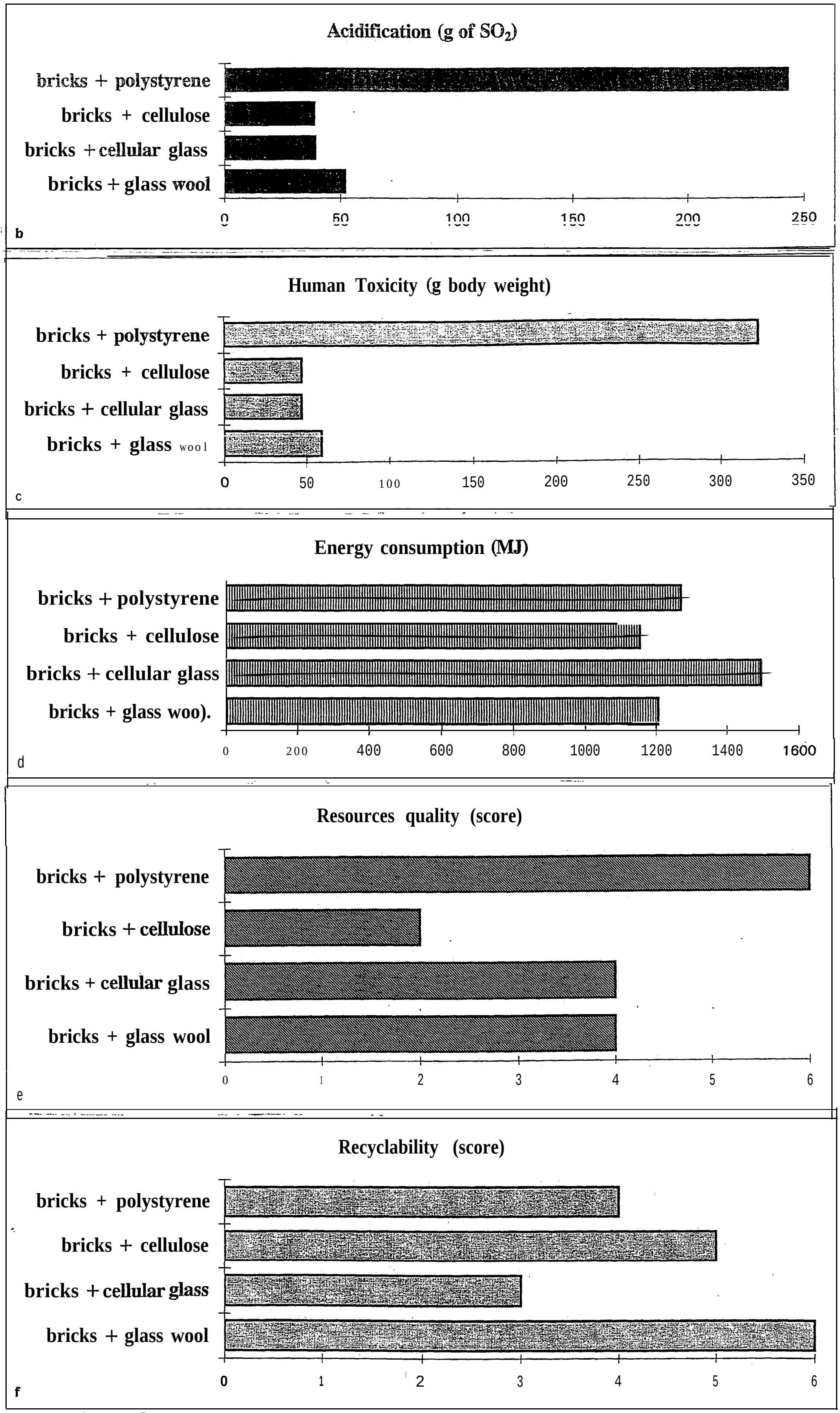


Figure 4b to 4f. Comparison among environmental profiles of insulated cavity walls having different insulating materials (continued from previous page)

2 Commentary on profiles

Profiles allow both to make a comparison among alternative technological solutions and to assess the consequences of different materials used in the same solution; in particular, the profiles reported in Figures 4a to 4f show how the use of different insulating materials within an insulated cavity wall modifies the contribution to the main environmental effects.

The analysis points out, for instance, that polystyrene implies more impacts as regards nearly all of the environmental effects (in particular, it proves to highly contribute to the greenhouse effect, human toxicity and photooxidation), yet it involves a more reduced energy consumption and a higher recyclability, since, through incineration, it is possible to recover the embodied energy.

Some remarks can be made about cellulose fibre. This material is considered to have a low environmental impact mainly because it is produced with recycled paper and in fact it has a low “quality of resources” profile; however, as regards environmental effects such as the “greenhouse effect” and “acidification”, cellulose fibre shows almost the same profiles as other insulating materials (excepted polystyrene).

3 Summary and conclusions

The results worked out in the research can be regarded as a contribution to designers’ choices, providing data and information in a readily available format that normally would be difficult to find and hence compared. Such results could be summed up as follows:

- implementation of a tool (the electronic sheet) for collecting, assessing and comparing environmentally relevant data; such a tool could be implemented for all the other technical solutions in buildings;
- comparison among 18 solutions of external vertical walls.

However, the analysis has revealed some difficulties: the availability of correct and comparable data, the unavoidable subjectivity of qualitative assessments, that can vary in relation to the context; the necessity to simplify the estimation of durability of the design solutions. The functional unit definition can also be improved, by introducing other parameters, in addition to the one of thermal transmittance: e.g., acoustic insulation, fire behaviour and mechanical performance.

This research should be implemented in order to deal with more reliable data and to be extended to other technical solutions of buildings. It is in fact increasingly urgent to provide designers with simple tools that improve their capability to make choices aimed at bringing about sustainable construction.

Acknowledgements

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Italiana Polistirolo Espanso) that have collaborated by providing the research and sector specific data.

References

1. AIA (The American Institute of Architects) (1994) *Environmental Resources Guide, New* York, USA
2. ANDIL (Associazione Nazionale degli Industriali del Laterizio, Italy) (1995) ***Dati*** *statistici sulle emissioni dei laterizi, Rome,* Italy
3. Astrup Jensen, A., (1993) Key *features for insulation products* - Draft, dkTekink Soborg
4. CML (Centre for Environmetal Science) (1992) *Environmental life cycle assessment of products: Guide,* Leiden, Holland
5. Federchimica (1995) *Primo rapporto ambientale Responsible Care - 1989-94,* Milan, Italy
6. SETAC (Society of Environmental Toxicology Chemistry) (1993) Guideline for life cycle assessment: a code of practice, Sesimbra, Portugal
7. Technical documentation provided by producers' associations.

"Recoverability" of building elements in recovery intervention

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Abstract

The present work takes in the themes about the rescue of building materials, i. e. the prevention and reduction of building debris and is founded on the concepts of sustainaible development and resource conservation.
The considerations from which the research presented during this article start, concern the difficulties in order to identify waste areas, and still less to assess the enviromental impact and the high cost for transport and dumping of the discarded material.
Therefore the expectation, since the planning phase, of what can be preserved and/or reused to reduce building debris quantity, becomes more and more important.
For us is also remarkable to deem many elements have to be preserved because of their intrinsic architectonic value or for their integration with the environment where they are put in or, still, like an historic evidence.
After the individuation of the necessity about the building elements evaluation, that serve by way of proem for each projectual choice, the work aim has been the description of a methodology that let to define in a well-pondered manner the "level of recoverability" of the element in order to be functional for the achievement of the set goals.
The worked-out methodology concern:
- the splitting up of the building into "intervention ambits", defined as a pool composed by elements and/or works, arranging in a common spatial ambit but having different functions and whose mutual interfacing relations have to be assessed;
- the accomplishment, for each intervention ambit, of an accurate investigation about health conditions and recoverability of the made-up building elements and their degeneration level;
- the accomplishment of an analysis concerning individual elements either under the valuation of the diagnostic angle fulfilled through the awarding of linked scores and the definition of a parameters sequence which enable the designer to decide whether to repair or to replace the element under consideration.
For each option a detailed form with related information is worked-out.
The originality of this work lies in the identification and definition of parameters and related scores that have to be specified in detailed forms and during the elaboration of the related forms. The parameters to be considered are not strictly referred to technological valuation, but they take into consideration also architectonic and operative aspect.
Keywords: Building recovery, recycling of construction materials.

1. Introduction

The present work stems from the necessity to single out tools able to manage the complexity of the problems related to recoverability of building materials in recovery interventions.
With the word “rescue” we refer especially to restoration and recovery interventions i.e. those are finalized to conserve the building and to assure that its function through a thematic pool of works which respecting the typological, morphological and structural elements permit a destination use compatible with it.
Such interventions include consolidation, restoration and renewal of building constitutive elements, introduction of accessory elements and plants requested by the modified use demands, removal of not related elements.
A building Knowledge phase [1], that we consider essential, must precede a rescue project it must be accomplished thoroughly and systematically.
Only the complete knowledge of the building as to specific historic, technological and functional references (construction techniques, materials, system types, construction date, original use, alterations, urban regulations, etc.) will allow properly oriented and timely arranged interventions , when necessary, for the maintenance.
A recovery project have to follow a precise path:
- the building knowledge through investigations in situ, surveys, etc;
- the determination of the building health conditions through specific procedures;
- the elaboration of specific forms related to health conditions of building in its complex and in its constitutive parts stressing the building pathologies and eventually their causes (etiology);
- the valuation of the convenience either to repair and/or to substitute damaged elements.

For a correct analysis the building have to be splitted up into “intervention ambits" defined as a pool composed by elements and/or works arranging, in a common spatial ambit but having different functions and whose mutual interfacing relations have to be assessed (i.e. in the intervention ambit “facade”, would be mandatory to valuate the interface problems between external frames and vertical external walls).
During the knowledge phase for each intervention ambit is necessary to accomplish an accurate investigation about the health condition and the level of recoverability of the constitutive building elements and their degradation level.
First of all, the concept of “recoverability” must be defined .
The word “recoverable material” is referred to material that can be reused and/or recycled.
From a conceptual point of view the two words “reuse” and “recycle” indicate two different concepts.
“Reuse” indicates a new use for the cast off product and is related to products or components that are reused as such, after verifications or functional control.
“Recycle” indicates the activity of processing debris.
It happens after plysical/chemical treatments in order to allow the production of secondary raw material, or energy or for purposes different from original.

2. Valuation of recoverability

The elements can be classified according to their recoverability level with regard to their recyclability o reusability,in the following way:
- constituent materials of not recoverable element, not recyclable and not reusable;
- not recoverable elements, not recyclable and not reusable;
- recyclable and/or reusable constitutive materials;
- recoverable elements for appearance not recoverable for performance;

- recoverable elements for appearance and for performance;
- recoverable elements , recyclable and reusable.

After examination of the recoverability degree of each element, the entire amb'it is evaluated to decide wich level of intervention will be chosen according to the specification of intervention types.

Building intervention levels are shown in hierarchical order from 0 to 6 and define what can be carried out at each level.

Level 0: Routine maintenance: internal and external paintwork, painting etc.;

Level 1: Remaking works of completion and finish materials: floors, sanitary wares, doors, windows, replacement of drain pipes, remaking of roofing, etc.;

Level 2: Complete remaking works of the plants included the replacement of waterpipes and under track elements (heating, wiring);

Level 3: Functional conforming works with displacement and addition of internal walls, bathrooms and services: remaking foundation, plants internal partitions, etc.;

Level 4: Strengthening works concerned loadbearing structures in situ (foundation, vertical, horizzontal and inclined structures).

Level 5: Replacement works of loadbearing structures (vertical, horizontal and inclined structures).

Level 6: Demolition and total rebuilding.

Once completed the procedure, it can be developed a technical-economic valuation of intervention, without forgetting the cost of waste disposal.

The related diagnosis, based upon the analysis of intervention ambit health conditions, and the valuation of different parameters will lead to define the intervention level.

The valuation whether or not it is convenient to repair and/or to substitute the damaged elements is not only based on diagnosys and economic data but it refers to others parameters.

For example after a building analysis, an element can be judged excellent regarding its performance but not proper for its appearance.

Viceversa an element below standard regarding its performance could not be substituable for its appearance.

Therefore we can conclude that substitution is not a necessary consequence of damage.

3. Parameters

The singled out tools are useful to reduce as much as possible the subjectivity of opinions related to elements health conditions based on use of words such as bad, middling, good; infact we think that such words are not able to describe the complexity of all factors involved.

Therefore a series of parameters have to be defined and used during analysis on each element through attribution of a combined score system; such scores will enable the designer to decide whether to restore or to replace the element under consideration.

The parameters to be considered will not only refer to technological valuation, but also to the architectural aspect.

Before evaluating the recoverability degree of building elements, the possible bonds (active) on the building have to be considered as determinant.

The analyzed parameters are part of a non exaustive list (open list) in which new specific parameters for a particular intervention can be later inserted.

The considered parameters are as follows:

- appearance: it is a parameter useful for valuation; in fact it can condition the decision because some elements could be not substituable for their intrinsic architectural value.
- use compatibility: the element must be compatible with its use.
- compatibility among materials; incompatibility among materials can produce pathologies of different importance.

- restoration and recovery costs: valuation of whether it is economically convenient to substitute or to maintain a degradated element should consider also the cost of transportation and dumping and/or storage of the replaced element; we should compare the cost of substitution of the element (interface problems included) with the cost of repair and maintenance of a new element with the cost of maintenance of a repaired element.
- morphological integration: the technical elements that are placed in the same intervention ambit must be adequate one with each other regarding their form;
- functional conformity: the element have to be conformed from the functional point of view to the new demands;
- enviromental respect: the element during its production whether in situ or when it is pulled down, must not damage the enviroment.
- correspondence to fundamental requirements such as: security, comfort, usability, integrability, appearance, management, enviroment protection.

Such requirements are related to fundamental specifications contained in Regulation CEE n. 106189.
Once completed the procedure, it will be possible to define wich level of intervention should apply and to determine a priori the quantity of discarded material should be dumped.
In any intervention ambit, each element will have score varying between 0 and 10 (0 = very bad condition; 10 very good condition), the addition will be done for each element and it could totalize a score variable between 0 and the maximum resulting from the number of parameters multiplyed by 10; it follows that, chosen the 50% value as a discriminant limit, the element will be substituted if the total score is under 50%; it will be maintened if the total score is over or equal to 50%.
After taking into account all parameters for each element, the intervention ambit, in its complexity, have to be considered.

4. Methodology

The worked-out methodology is based on the splitting up of the building into “intervention ambits" as these definied in the introduction and its development is composed. by three phases:

- decription;
- estimation;
- intervention.

For each ambit three forms sequenced with one of the three phases are looked on.
The first phase concern the development of an accurate investigation about the health conditions and recoverability of the constructive component element, and their degradation level.
The individuation and description form (Table 1) is related to this phase.
Instead the investigation/valuation form concern the second phase (Table 2).
In this form each element of the intervention ambit is inspected (directions are related to the inspection level and to the quantity to be inspected) and it is valued reused or not.
The valuation for each element, based either on value or diagnostic analysis, should be estimate by a score coming out from a total points for each parameters.
At the end to support the intervention phase an operative form (Table 3) is seen.
This form supply for indications concerned interventions and procedures for their execution.

INDIVIDUATION FORM OF ELEMENTS INTERVENTION AMBIT n° 2.1.1 FACADE N-W .			drawing up date FORM N° 2.1.1.a			
ELEMENTS	SPECIFICATION [1]		REFERENCE DATA			
	n°	Specification item/Survey	Quantity u.m.	Exec. data	Constr. details n°	Product form n°
Wall system	hk	Masonry bearing walls made up of bricks (two bricks thickness) bonded together with mortar Type S (dimension bricks are 5.5x12x25 cm.) :	mc 4,68	1960	X	10.3
	xy	Two coat plaster: scratch coat made by mortar of hydraulic lime and concrete and floating coat by mortar of lime putty	mq 180	1960		
	zh	Double color-washing with water painting of acrylic resins in watery emulsion, painted on brush	mq 180	1975		
Outlines of doors and windows, windows-sills e door-sills.	rt	Outlines of doors and windows, windows-sills and external door-sills 3 cm. thick and buffed on visual parts (for windows with dripstone)		1975	W	1,2
Windows/Doors	uq/ yh	Windows/Doors casement, in larch, mm. 45 thick, operating sash side-hinged: sash frame with banding, (with the place for the glass into sash frame, glazing bead for glass and dripstone), windows hardware in bronzed steel and brass handles	mq11,88 n°11 mq	1960 2,64 .	Y/Z	7.5/7.6
		Shutters elements made by fir-wood, mm. 25 thick, life-size n° 12	n° 1			
Shutters	hh	Spring casement stay oven-baked painted	mq14,52	1975		2.1
Casement stay	dd	Rainwater pipes in copper plate, mm. 6/10 thick,and with a mm. 100 of diameter,	n° 24	1975		
Eaves and waterspout	el	coupling filled with special sealing, fastened to load-bearing structures with screw and expansion small plugs	ml. 20	1975		3.9
		External lighting fixture				
Electrical system	hj	Bell-push and Intercom board	n° 1			
Element of public estate	px/ts	Electric cables for public energy distribution	n°1+1	1975		
		lluminating apparatus for the public lighting net steel.	n° 1			3.7/3.10
		Pipelines for gas distribution				
		Plate for toponymy indications				

Table 1 Individuation form of elements ([1] Number and items with reference to specification or to price list)

INSPECTION AND VALUATION FACADE N-W			INTERVENTION AMBIT n° 2.1.1				drawing up date FORM N° **2.1.1.b**	
ELEMENTS	SPECIFICATION[1]			INSPECTION				
	n°	Specification item/Survey (synthetic words)	**Exec** Date	Inspection Quantity	* Inspection type	** Score	Judgement	Interv. Quantity
Wall system	hk	Masonry bearing walls	1960	mq. 180	Visual and instrumental control	66	Recoverable	6ml 25 mq
	xy	Outside plaster	1960	mq. 180	Percussion	55	Recoverable	180 mq
	zh	Painting	1960	mq. 180	Visual control	30	Not recoverable	
Outlines of doors and windows, **windows-**sills e door-sills.	**rt**	Outlines of doors and windows, window-sills and door-sills	1960		Visual control	62	Recoverable	180mq
Windows/Doors	**uq/yh**	Windows/Doors casement	1960	**n°** 1 **1+1**	Visual control/reckoning	58	Recoverable	12
Shutters	hh	Shutters	1975	**n°** 12	Visual control	52	Recoverable	12
Casement stay	dd	Spring casement stay	1975	**n°** 24	Visual control	25	Not recoverable	24
Eaves and waterspout	el	Rainwater pipes	1975	ml 20	Visual control	21	Not recoverable	20 ml
Electrical system	**hj**	Illuminating apparatus for outside	1975	**n°** 1		28	Not recoverable	
	px/ts	Bell-pushes /Intercom board	1975	**n°** **1+1**	Visual control	35	Not recoverable	
Element of public estate		Public **eletric** cables			Visual control			
		Gas pipelines						
		Public illuminating apparatus			Visual control			
		Plate for toponymy indications.			Visual control			
					Visual control			
					Visual control			

* REMARKS	PARAMETERS **(score from 0 to 10 for each parameters)**	
Presence of rising humidity /Plaster peeling/Washed out painting Casement stay gratly rusty/Rainwater gratly damaged For **calculs** related to frames see Annex 1 “Inspection valuation form”	Appearance Compatibility among materials Use compatibility Restoration and recovery costs	Morphological integration Functional conformity Environmental respect Correspondence to fundamental requirements
	** TOTAL **(score from 0 to 80 for all parameters)**	

Table 2 Inspection/valuation form ([1] Number and items with reference to specification or to price list)

OPERATIVE FORM FACADE N-W			INTERVENTION AMBIT N° 2.1.1				drawing up date FORM N° **2.1.l.c**
ELEMENTS	INTERVENTION GOAL [1]		INTERVENTION TYPE [2]				PROCEDURES
	n°	Specification item/Survey (synthetic words)	Interv quantity	Inspect. form	N°	Specification items for recovery intervention (synthetic words)	Permissions, technical rules, fiscal and/or financial reduction..
Wall system	hk	Masonry	6ml		YX	Masonry mechanical cut	
	xy	Outside plaster	25 mq		XW	Demolition and renewal into spotted areas	Put syndic through
	zh	Painting	180 mq		ZH	Complete painting	See City Colour Plan
Outlines of doors and windows, windows-sills e door-sills.	rt	Outlines of doors and windows, window-sills and door-sills				Cleaning and sealing	
Windows/ Doors	uq/	Windows/Doors casement				Removal painting/plaster/priming/ revarnishing	
Shutters	yh	Shutters	12			Removal painting/plaster/priming/ revarnishing	
Casement stay	hh	Spring casement stay	24			Complete replacement	
Eaves and waterspout	dd	Rain water pipes	20 ml			Complete replacement	
Electrical system	el	Illuminating apparatus for outside				Complete replacement	
	hj	Bell-pushes /Intercom board				Complete replacement	
Element of public estate	px/ ts	*Public eletric cables*					Put Electric Energy Agency through
		Gas pipelines					Put Gas Spplying Agency through
		Public illuminating apparatus					Put Municipality through
		Plate for toponymy indications					

Table 3 Operative form ([1] Number and items with reference to specification or to price list)
([2] Number and words related to recovery specification, to be consulted for the whole word)

5. Conclusions

The methodology described in the present work is applicable to recovery interventions and allows to determine in advance the extent of the demolitions and consequently the quantity of materials to be dumped, reused and/or recycled.
Moreover, such method let us relate quickly each project choice to the production either of debris or of recovery material. Such a result can be expressed in specific forms.
It is important to underline that it is an experimental method still in fieri that offers a wide list of parameters list; such parameter may allow the best project strategy.

6. References

1. Motteu, H. and Rousseau, E., (1992), Le remploi des dechets dans l'industrie de la construction. *CSTC Magazine,* pp. 21 - 30.
2. Dal Zio, E., Dal Piaz, V., Paparella, R., Rinaldi, E. and Vergine F., (1994),, *Impostazione* ***di un sistema esperto*** *applicato alle scelte* ***di conservazione in uso*** *e* ***di*** *recupero del* ***patrimonio*** *edilizio* ***pubblico,*** Università di Padova, pp. 164.
3. Dal Zio, E., Paparella, R., Rinaldi, E. and Vergine F., (1995), A computerized support targeted to managing buildings in service. ***Report*** *IABSE,* ***Colloquium: "Knowledge Support Systems in Civil Engineering*";*** Bergamo, vol. 72, Zurich, IABSE-IAPC-IVBH, pp. 167-176.
4. Van Dessel, J. and Vyncke, J., (1995), The European policy on the management of construction and demolition waste, *ECOTOP* ***9.5,*** pp. 1-8.
5. Lofflad H., (1997), Meno Rifiuti nell'Edilizia: La casa completamente riciclabile, ***Architettura*** *naturale*, 1/97, pp. 36-39.
6. Ruch, M., Sindt, V., Schultmann, F., Rentz, 0. and Vimond, E., (1997) Deconstruction selective: experimentation a Mulhouse, ***CSTB Magazine*** n° 101.

Alternatives to Plasticized PVC for Flooring Tiles

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Abstract
Materials used in building applications are currently selected based on the principal criteria of cost and performance. However, sustainability is increasingly becoming an important selection consideration. The impact of a building material on the indoor environment must thus be addressed. For flooring applications, calcium carbonate-filled poly(vinyl chloride), PVC, has long been the material of choice for both flexible sheeting and tile products. PVC-based formulations have the necessary combination of physical properties and low cost to suit the needs of the application. However, these formulations must be processed with plasticizers, which have recently raised some concerns from a sustainability point of view. Plasticizers are low molcular weight additives that can contribute to the generation of volatile organic compounds, and to the growth of potentially hazardous microorganisms over the lifetime of the flooring product.

In the research work reported here, calcium carbonate-filled formulations based on polyolefin plastomers, POP, are prepared in a laboratory-scale mixer, and their physical/mechanical properties are studied for flooring applications. Plastomers are olefin copolymers synthesized using new metallocene catalyst technologies. These technologies allow the physical and mechanical properties of plastomers to be tailored to suit specific applications. The POP plastomer used in this research is a copolymer of ethylene and octene, and does not require any plasticizers for processing. The key physical/mechanical properties of the calcium carbonate-filled POP, which include tensile strength, elongation and impact strength, are found to compare very favourably to those of PVC formulations at filler loadings of 200 phr. In addition, the filled POP formulations are able to incorporate a significant amount of post-consumer recycle high density polyethylene while maintaining adequate physical properties. These results indicate that calcium carbonate-filled POP should be studied further as a more sustainable alternative to filled PVC for flooring applications.

Keywords: flooring tiles, plasticizer, polyolefin plastomer, poly(vinyl chloride), recycled high density polyethylene.

1 Introduction

PVC has a wide variety of applications. It is second in volume only to polyethylene, with sales in North America of 6.2 billion kg in 1995 [1]. Roughly 53% of PVC resin production is used in the building industry [2]. Indoor applications include wall coverings, coatings, flexible flooring, baseboards, blinds, and profiles for windows and doors. Unmodified PVC homopolymer is quite stiff and rigid. The same is true of the PVC copolymers used in flooring applications. These physical characteristics can be altered through the addition of plasticizers, low molecular weight additives that act to reduce molecular binding forces and increase flexibility. Typical families of compounds used as plasticizers include the phthalates and benzoates. The plasticizers are miscible with both homopolymer and copolymers, and can thus be present in a wide range of concentrations depending on the finished product. Extruded profiles require relatively low levels, while the plastisols used for flexible flooring, and the . organosols used for coatings, require much higher plasticizer concentrations. Plasticizers have been traditionally considered to be inert and non-volatile. However, there is growing evidence that plasticized PVC products can be a source of volatile organic compounds (VOC) in buildings [3].

Plasticizers are known to migrate to the surface of a PVC product over time. At the surface, they may become volatilized, or subjected to microbial degradation. This kind of degradation is especially prevalent in humid environments. As a result, plasticized PVC flooring products often suffer from discoloration due to unsightly bacterial and fungal growths. In addition to the esthetic drawbacks, microbial growth on plasticizers also presents a number of risks to human health and well-being. The microbes break down the plasticizer molecule into more volatile components, which are subsequently released into the enclosed building environment. Inhabitants may thus be subjected to long-term exposure of low-level VOC. The microorganisms may also increase the susceptibility of the polymer chain itself to biodegradation, leading to the possibility of volatilizing halogenated organics. Finally, the plasticized surfaces may provide a breeding ground for microbes, which can then spread throughout the building. These considerations point to the need for research into more sustainable alternatives to PVC-based indoor building materials.

In many ways, plasticized PVC is ideally suited to flooring applications. The PVC imparts excellent impact resistance, stiffness and toughness to the final product, even at filler loadings in the range of 200 to 300 phr (parts per hundred resin).

Conventional polyolefins, produced by Ziegler-Natta catalyst technologies, have been unable to match the balance of properties required for flooring applications. However, new families of polymers have recently been commercialized based on metallocene catalysis. Metallocene catalysts allow for site-specific polymerization of olefins and other monomers. The resulting polymers tend to have narrower polydispersity, a controlled degree of branching, a controlled length of the branches, and the ability to incorporate a variety of comonomers into the backbone. These polyolefin copolymers may be termed either a polyolefin plastomer (POP), or a polyolefin elastomer (POE), depending on whether the comonomer amount is low or high, respectively. Because of this flexibility in polymer synthesis, metallocene-based resins have a wider range of physical properties than traditional polyolefins [4]. The properties can also be carefully controlled to suit specific applications [5]. For this reason, the new resins are making quick inroads into packaging, wire and cable, and some specialty markets [6]. In the preliminary study presented here, formulations of filled POP have been produced at the laboratory scale, and tested for flooring applications.

POP-based formulations can have important advantages over PVC-based ones. The first advantage is that filled POP can be processed without the use of plasticizers, thus avoiding problems associated with VOC emissions and microbial degradation. The second advantage in using POP is the potential for incorporating post-consumer recycle. Over 75% of recycled plastics is estimated to consist of polyolefins. Incorporation of these materials into PVC flooring tiles would lead to large reductions in physical properties because of the poor miscibility between PVC and polyolefins. POP, on the other hand, is compatible with recycled polyolefin resins, which could thus be used as extenders to lower costs. The effect of recycle content on POP formulations is therefore studied as well in this work.

2 Methodology

The methodology section is divided into a description of the materials used, and of the experimental procedures for compounding and testing the physical and mechanical properties.

2.1 Materials

In order to evaluate POP relative to PVC as a resin for flooring tile applications, formulations were prepared using both types of resins. These formulations are indicated in Table 1.

The PVC resin, Oxy 1810, was obtained from the Occidental Chemical Corporation (USA). It is a PVC copolymer with vinyl acetate (VAc), having a specific gravity of 1.37, and a VAc content of 9.7%. The POP resin, Affinity PF 1140, was obtained from Dow Plastics (USA). It is a copolymer synthesized from ethylene and octene monomers, and has a specific gravity of 0.895, and an octene comonomer content of 14.0%. The calcium carbonate was obtained from Steep Rock Resources in Perth, Ontario. The grade used was Snowhite 12, which has a specific gravity of 2.71, and a mean particle size of 12 microns. For PVC formulations, a technical grade of dioctylphthalate (DOP) was used as a plasticizer, and dibutyltin dilaurate (DBTL) was used as a heat stabilizer. For both polymers, a technical grade of stearic acid was used as an external lubricant. Both stearic acid and DOP were obtained from Fisher Scientific. DBTL was obtained from American Chemicals Ltd.

Some formulations were prepared with post-consumer recycle high density polyethylene (PC-HDPE), obtained from Enviroplast Inc. of Ville d'Anjou, Quebec, and has a specific gravity of 0.93 and a melt index of 0.1 dg/min. Formulations were also prepared with both POP and PC-HDPE in concentrations totalling 100 phr. PC-HDPE contents of up to 80% were tested in these formulations.

Component	PVC Formulations	POP Formulations
	Concentration, phr	Concentration, phr
Resin	100	100
Filler, $CaCO_3$	**200**	**200**
Plasticizer, DOP	**35**	**-**
Stabilizer, DBTL	**3**	**-**
Lubricant, stearic acid	**2**	**2**
PC-HDPE	**0**	**20, 50, 80,** 100% of total resin content

Table 1. PVC and POP-based formulations prepared and tested.

2.2 Experimental Procedures

Raw materials were compounded in a Haake Rheomix 600 equipped with roller blades. The operating conditions for the mixer are summarized in Table 2.

Formulation	T, ^oC	Blade speed (rpm)	Mixing time (min)
PVC-based	140	**40**	**6**
POP-based	175	**60**	10

Table 2. Operating conditions in the laboratory mixer.

The compounded material from the mixer was then molded by compression using the following procedure. The sample was placed in the mold on the heated platens for **5** min. in order for the polymer to melt. It was then kept under pressure for 3 min., and subsequently air cooled under pressure at room temperature for 5 min. The platen temperature was 158 ^oC for PVC formulations, and 178 ^oC for POP ones. For POP formulations containing PC-HDPE, the molding procedures were modified slightly. The platen temperature used was 178 ^oC, but the melting time, the time under pressure, and the cooling times were 7 min., 4 min., and 10 min., respectively. From the molded samples, specimens were prepared for the tensile and impact tests. Specimens for tensile tests were cut with the Type V die specified in ASTM D638 [7].

Tensile and impact tests were performed for all PVC and POP-based formulations. The tensile tests were carried out in accordance with the procedures outlined in ASTM D638, using an Instron universal testing machine at a crosshead speed of 5 mm/min. for POP/PC-HDPE blends, 10 mm/min. for PVC samples, and 20 mm/min. for POP samples. Impact tests were carried out using the notched Izod procedure given in ASTM D256 [8] with a model 92T Tinius Olsen impact tester.

All the specimens for tensile and impact strength were tested one week after their preparation. They were conditioned at 23 ± 2 °C and 50 ± 5% RH for 48 hours before testing. All of the indicated values are an average of at least five determinations. The coefficients of variation inferior to 10% were taken into account for each set of specimens tested.

3 Results and Discussion

Table 3 summarizes the results obtained in the tensile and impact tests for the formulations described in Table 1.

Resin	Yield Stress, MPa	Break Stress, MPa	Elongation, %	Impact Strength, J/m
PVC	2.77	5.55	336	154
POP	3.92	**7.29**	1420	299
PC-HDPE	-		0	72

Table 3. Results of tensile and impact testing.

The tabulated data show that the physical properties of the POP-based formulations compare very favourably to the PVC-based ones. In particular, the higher values in elongation and impact strength point to superior toughness in the POP samples. This point is significant since high filler loadings have large adverse effects on the toughness of composites made with conventional polyolefin resins. The results also indicate that the POP resin can likely accomodate calcium carbonate loadings in excess of 200 phr while maintaining adequate physical properties.

Table 3 shows that formulations containing solely PC-HDPE as the resin have very poor mechanical properties. The calcium carbonate loading of 200 phr is clearly much too high for the PC-HDPE to function as an effective binder. Formulations using a blend of POP and PC-HDPE resins were therefore prepared and tested.

Mechanical properties were determined for the POP and PC-HDPE formulations containing recycle contents of 20%, 50% and 80% of the total polymer concentration, as indicated in Table 1. These results are presented below in Figures 1 through 4. Figures 1 and 2 show an increase in yield stress and a decrease in break stress with increasing recycle content. This behaviour is characteristic of a loss in the elasticity of the blend upon addition of the recycle resin, and is to be expected. The dramatic decrease in elongation shown in Figure 3 is also not surprising, since elongation is a property known to be sensitive to the previous thermal history of recycled resins. In fact, the incorporation of only 20% PC-HDPE leads to an almost threefold reduction in sample elongation. The loss of elastic properties due to the incorporation of recycled resins is well documented, and is frequently translated into a decrease in toughness. However, for the case of POP containing PC-HDPE, there is a notable increase in impact strength, as seen in Figure 4. In fact, there is an almost 40% increase in the impact strength when 50% PC-HDPE is incorporated into the POP formulation. This surprising result is due to the close chemical similarity of the HDPE and POP macromolecules - both being polyolefins. Thus, the PC-HDPE appears to be similar to an impact modifier in increasing toughness. The incorporation of post-consumer recycle into POP-based flooring tile formulations at fairly high loadings appears to be quite feasible based on this study of physical properties alone.

4 Conclusions

A polyolefin plastomer has been used to produce formulations containing 200 phr calcium carbonate. Similar formulations based on PVC copolymers are typically used in the flooring industry for flexible tiles and sheets. The POP-based formulations were found to have physical properties superior to the PVC ones. In addition, the POP formulations offer two significant advantages over PVC. Firstly, no plasticizers are required in their production, thereby eliminating a hazardous class of chemicals currently used in PVC-based flooring products. Secondly, POP formulations were shown to be capable of incorporating large amounts of post-consumer high density polyethylene with acceptable reductions in key physical properties. In fact, the impact strength of recycle-containing POP formulations was found to increase. Such a result would not be possible for the incorporation of recycled polyethylene into PVC-based formulations. It can thus be concluded that POP resins warrant further' detailed investigation as more sustainable alternatives to PVC in formulations for flooring products.

5 Acknowledgements

We would like to thank the EJLB Foundation for its role in funding this work. Two of us are also indebted to the Faculty Research Development Program of Concordia University for partial support of this research.

6 References

1. Summers, J.W. (1997) *J. Vinyl Additive Technol.*, Vol. 3, No. 2, p.130
2. http://www.compulink.co.uk/~plasticsdata/pvc/pvcuse.hti

3. Morfini, L., Dessy, P. and Nironi, L. (1997) *Proc. 2nd Int. Conf. Buildings and Environment,* Vol. 1, Paris, June 9-12, p.181
4. Brockmeier, N., Arzoumanidis, G., Karayannis, N. and Stein, N. (1996) *Chemical Engineering,* Vol., 103, No. 9, p.90
5. Zamora, M., Miller, T. and Brennan, A. (1997) *Plastics Engineering,* Vol. 53, No. 5, p.75
6. Wigotsky,V. (1995) *Plastics Engineering,* Vol. 51, No. 7, p. 16
7. American Standards for Testing and Materials (1993) Method D638-82, Vol. 8.01, p. 65
8. American Standards for Testing and Materials (1993) Method D256-93a, Vol. 8.01, p. 1

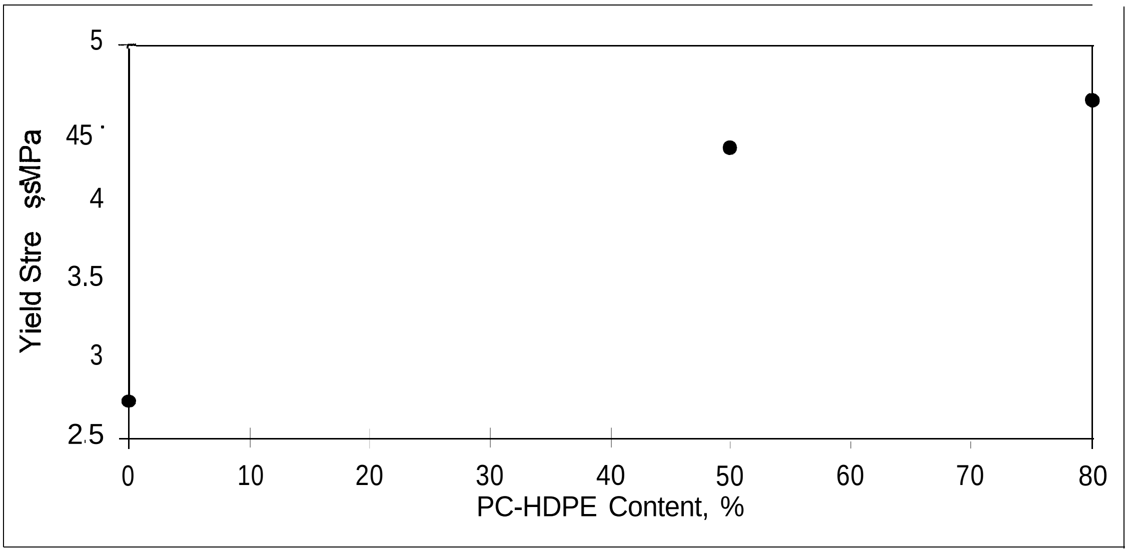

Figure 1. Effect of PC-HDPE on the yield stress of POP formulations.

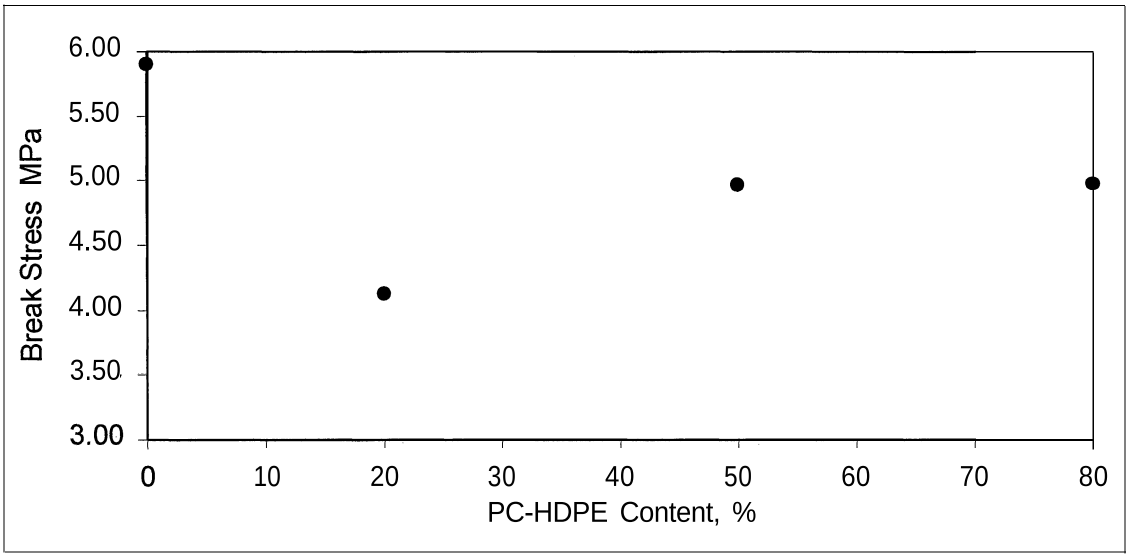

Figure 2. Effect of PC-HDPE on the break stress of POP formulations.

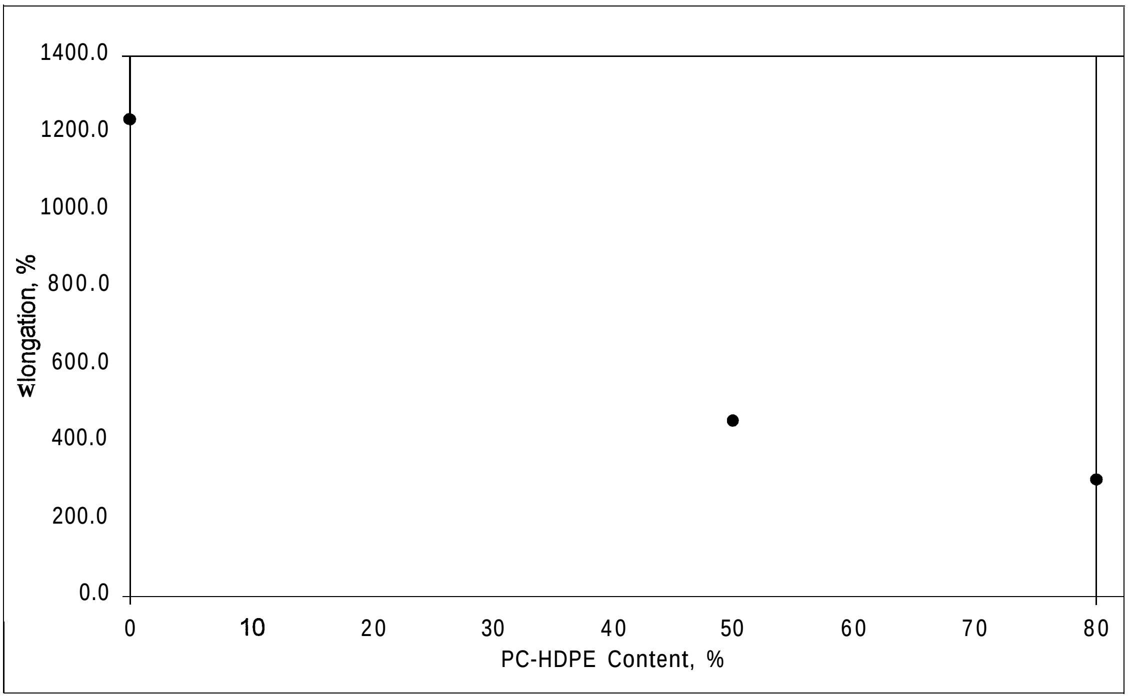

Figure 3. Effect of PC-HDPE on the elongation of POP formulations.

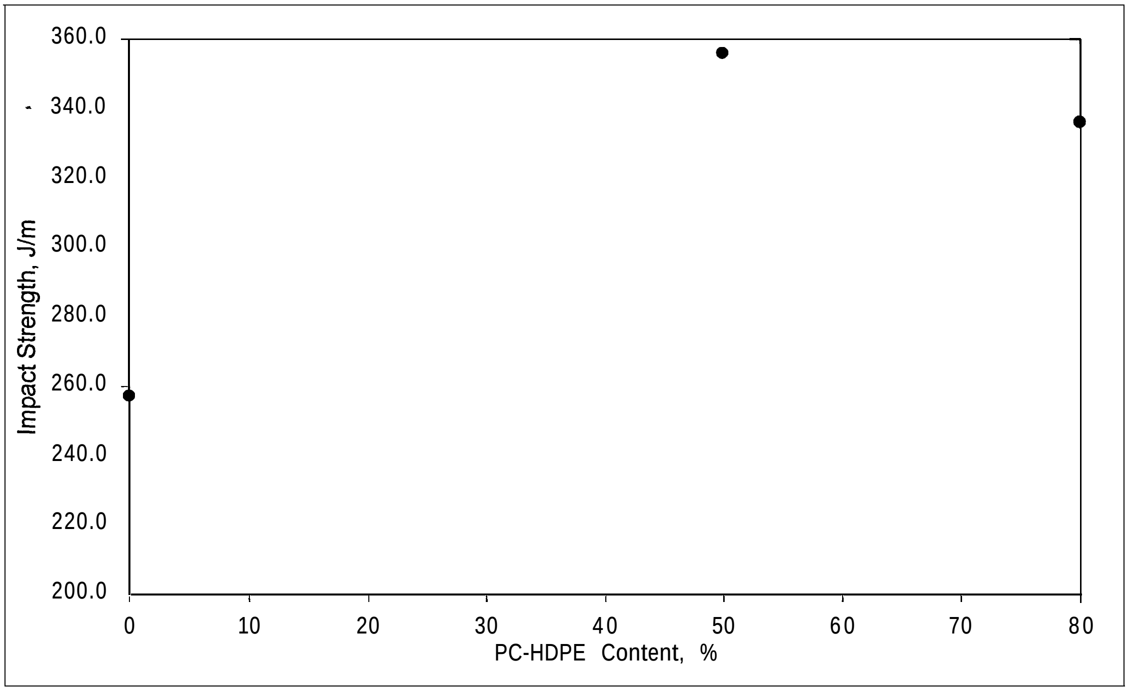

Figure 4. Effect of PC-HDPE on the impact strength of POP formulations.

Application of aggregates out of construction- and demolition waste in road constructions and concrete

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Abstract

This paper describes the reuse of construction and demolition waste as aggregates in road constructions for subbase layers and in concrete. From the total amount of 14 Mton produced every year ca. 85% is recycled in this way. The applications are based on results of research programmes running since 1980. Also, specifications are made. In addition to the technical quality, the environmental properties of the aggregates were investigated. In The Netherlands these aggregates have to meet the demands in the Materials Order Decree. This concerns composition and leaching limits. To meet these limits the demolition process and the upgrading of the outcoming waste have to be executed in such a way that the recycled aggregates are not polluted with for example asbestos, heavy metals or PAH.

Therefore a quality certification system is developed which describes the process to be followed and the quality control of the resulting materials. The quality certificates integrate the technical and environmental aspects in one procedure.

Because of the good outlook for application of these aggregates in future the authorities decided that dumping of construction and demolition waste is forbidden in the Netherlands since April 1st 1997.

The economical aspects of the applications described in this contribution are until now in favour for use in road constructions. Replacement of sand or gravel in concrete is most of the time not cost saving until now.

Keywords: summary of certification, environment, recycled aggregates

1 Application of aggregates out of construction- and demolition waste in road construction and concrete

In the Netherlands, 85 % of construction- and demolition waste is processed and made suitable for application in road construction or in concrete construction. Asphalt too is largely reused.
Table 1 reflects the most important applications.

Table 1. Field of application of Recycled aggregates

type of recycled aggregates [1)] application	RCA	RA	RMA	RHMA	RSA	RCS	AG	BAG
road construction hardening layer out of stone-mixture	+	+	+	+	-	-	-	-
stabilised layer	-	-	-	-	-	-	-	+
sand for embankment and supplement	-	-	-	-	-	+	-	-
sand for sandbed	-	-	-	-	-	+	-	-
supplement in • meagre concrete • (tar containing) bounded asphalt aggregate • asphalt mixtures	 + - -	 + - -	 + - -	 - - -	 + - -	 + + -	 - + +	 - - -
concrete construction supplement in concrete	+	+	+	-	+	+	-	-

1)

RCA = recycled concrete aggregate
RA = recycled mixed aggregate
RMA = recycled masonry aggregate
RHMA = recycled hydraulic mixed aggregate
RSA = recycled sand aggregate
RCS = recycled crusher sand
AG = tar containing asphalt aggregate
BAG = bounded tar containing asphalt aggregate

1.1 Production of recycled aggregates

The care with which the producer accepts the construction and demolition waste and with which he then produces recycled aggregates is determining the quality of the recycled aggregates.
Procedure of acceptance and processing of construction and demolition waste into recycled aggregates and the delivery of these at the customer can be seen as a primary

process. To support this primary process other processes like for example, purchasing, selling, maintenance and management of the material, etc. have to be recognised.

Means for discussion of the subject is a clear, uncomplicated and by that fast accessible description of the primary process given in the form of an elementary process diagram (see fig. 1). With it the in enclosure A entered technique diagram has been used.

In the process diagram the elementary process is reflected with, directly linked, a verification of points in the process, whereas careless handling has a direct effect on the end quality of the recycled aggregates.

*Explanation of the in fig. **1** represented process diagram for the procedure at acceptance andprocessing of construction and demolition waste.*

1. **Inspection at location at source of supply**
   If possible, an inspection of the for demolition due object or building object has been performed by which one has registered the for reprocessing suitable materials.
2. **Arrival of construction and demolition waste**
   The construction and demolition waste will be evaluated.
3. **Identification at means of transport**
   The cargo then visually will be judged on quality and type. The acceptance regulation shows which requirements the incoming material has to meet.
4. **1” acceptance**
   If the cargo successfully has passed through the preceding phase further handling can follow.
5. **Weighing**
   The cargo will be weighed and administratively incorporated. Administration takes place according to an established procedure. The at least to be registered information’s are adapted into this guideline.
6. **Dumping of construction and demolition waste**
   The cargo will be dumped and then, in second place, visually judged on quality and type. The requirements the construction and demolition waste has to comply with are stated in the acceptance regulation.
7. **2^{e} acceptance**
   On account of the visual judgement the cargo can be approved or still be refused.
8. **Approved construction and demolition waste**
   The construction and demolition waste will be separately stored by sorts.
9. **Transportation**
   The construction and demolition waste will be transported to the processing site.
10. **Pre-sieving**
    The material with a grading < 10 mm can optionally be sieved, depending on the environmental quality of the fine fraction. The material, called crusher sieve sand, that hereby will be released, will separately be stored.

11. **Crushing**
The remaining material will be crushed.

12. **Selection**
During transportation to the main sieve installation, irregularities are removed out of the material (iron by way of a magnetic band, wood by way of air infuse or rinsing with water, other contamination's by manual selection).

13. **Sieving**
The material will be sieved on various fractions. Upper sieve (> 40 mm) will once again be crushed.

14. **Selection (separate)**
Wood and other light metals are manually and or mechanically removed.

15. **Recycled aggregates**
The generated recycled aggregate will be tested according to the requirements set in this regulation. If the lot will be rejected it can be retreated or separately stored and removed as rejected material.

16. **Storage**
The recycled aggregates will be stored separately, by type/class.

17. **Recycled aggregates in storage**
The storage is organised as such that mixture and/or contamination is impossible.

18. **Purchase**
During delivery various data's are registered according to set procedures. The recycled aggregate can, in accordance with the specifications of the buyer and corresponding with the requirements set in this assessment guideline, be delivered.

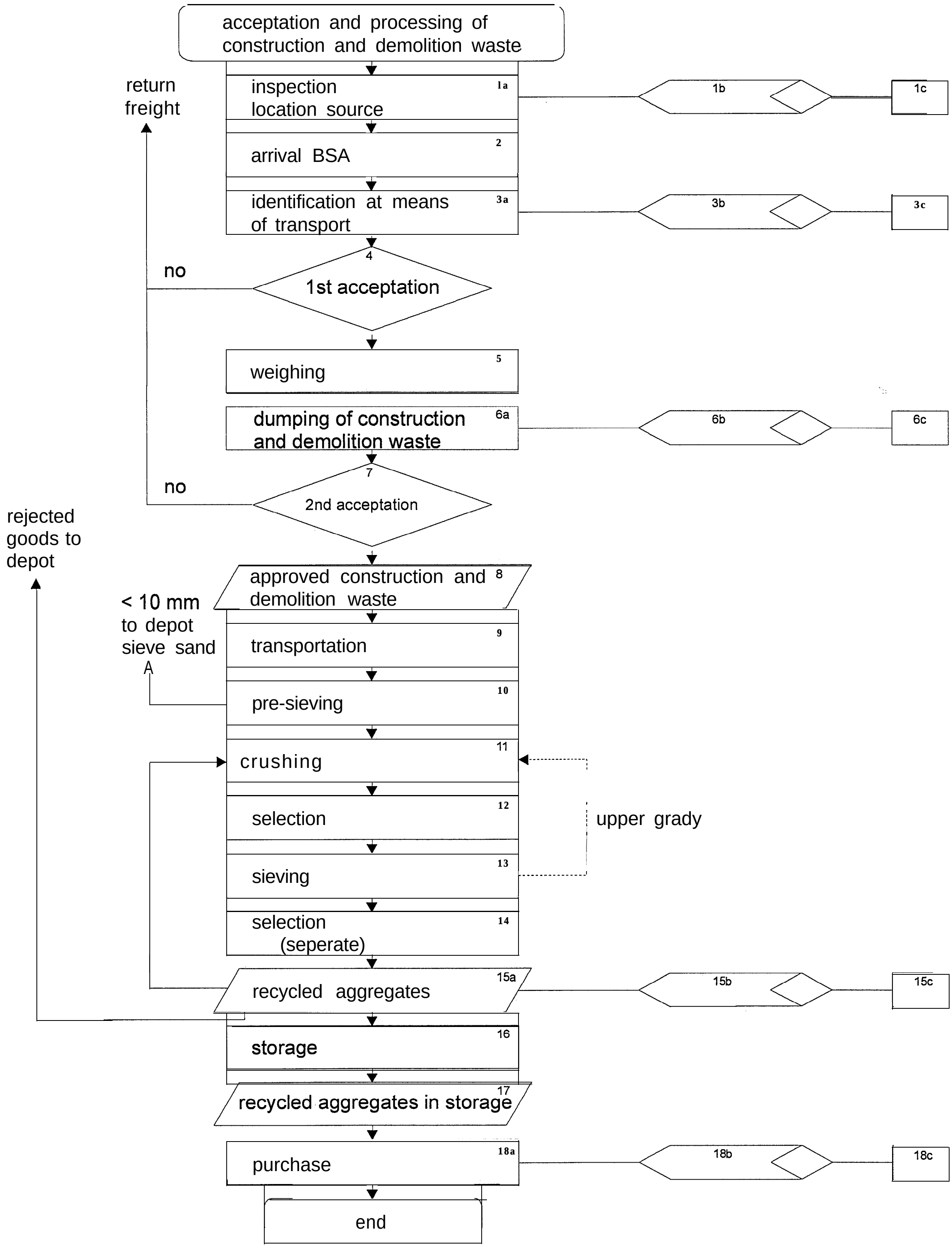

Figure 1. Example of a process diagram for the standard procedure during acceptation and processing of construction- and demolition waste.

1.2 Technical requirements road construction

A subbase of stone material has to improve the supporting power, must be good compacted and has to be resistant against action of moisture and frost. Recycled concrete- and masonry aggregates are, due to the thorough research and to an increasing degree of projects gained experience, fully accepted as qualitative high-grade stone subbases. Recommended is not to mix the recycled aggregates with other primary or secondary raw materials. Both from the engineering and environmental point of view this often is not leading to an improvement of the aggregates; through blending with the usually qualitative inferior products negative associations rapidly can occur. Furthermore there is a lack of experience with reference to suchlike mixtures which already has been gained with recycled aggregates. Incidental fantasy mixtures therefore have to be avoided. Application could, on term, bring the application of alternative materials in danger. Tables 2-4 summarise the most important Dutch specifications for recycled aggregates.

Table 2. Summary of requirements of compilation

	main component	**side component**
recycled concrete aggregate	min. 80% crushed concrete with dry density > 2100 kg/m^3	max. 10 % different stone and max. 5 % asphalt
recycled masonry aggregate	min. 85% crushed stone with dry density > 1600 kg/m^3	max. 15 % different stone and max. 10 % asphalt
recycled mixed aggregate	min. 50 % crushed concrete with dry density > 2100 kg/m^3 and max. 50 % stone with dry density > 1600 kg/m^3	max. 10 % different stone and max. 5 % asphalt

The technical qualities of recycled concrete aggregates practically are comparable with the recycled mixed aggregates. For application of stone mixtures as constructional road in subbases and as supplement and embankment, technical requirements are recorded in the so-called Standard specifications for roads (RAW).

Table 3. Requirements for subbases according to the Standard specifications for roads (RAW) 1995.

Requirements for subbases
• no foreign components • crushing factor higher the 0,65 • spreading of granules within limits, determined of sieves between C445 and 20 (m) • max. 10 % (m/m) round and unbroken pieces of sieve C4

Table 4. Requirements for materials on behalf of replenishment and embankment according to Standard specifications for roads (RAW) 1995

Requirements for materials on behalf of replenishment and embankment
• the materials has to be of mineral origin
• the material has to be inert that means for example not to dissolve in water
• the material may contain a portion of fine parts < 63 (m of 50 % m/m). In practice most of the times the requirement for sand will be handled for subgrade (max. 15 % (m/m) < 63 (m)
• the material may not contain more then 3 % (m/m) organic material
• in order to be used as embankment material the material has to be crushed to max. 45 mm. The created product has to have a regular distribution of granules in order to be able to compact. By reason of stability and possibility of compacting it seems to be advisable to handle, temporary, the distribution of granules of stone founding material 0/40 as basic assumption.

1.3 Technical requirements for application in concrete

Recycled aggregates have in comparison with gravel deviating properties. One has to consider these properties during composing of concrete blends and during processing of concrete mortar.
Recently the old NEN 5905: 1988 “Supplements for concrete, sand and gravel” was replaced through NEN 5905: 1997 “Supplements for concrete, materials with a volume mass with at least 2000 kg/m^3”.
In the revised version are for the application of recycled concrete aggregates and recycled masonry aggregates, respectively the CUR-recommendation 4 “recycled concrete aggregates as supplement of concrete” and the CUR-recommendation 5 “recycled masonry aggregates as supplement of concrete” written down.
Limiting values set to contamination have to do with various strength and durability aspects.

Among others:

- delaying influence on cement hardening;
- corrosion of reinforcement (chlorides);
- swelling under the influence of absorption of moisture (for example wood);
- formation of etringite (swelling through for example plaster);
- alkali – silica reactivity (for example Pyrex glass);
- decrease of pressure strength) for example asphalt.

In the table mentioned below a summarising of the most important requirements is given.

Table 5. Brief summary of the most important requirements made rule for aggregates at application in concrete according to NEN 5905.

Variable	Unit	Requirement	Definition method .
Distribution of aggregates		comparable with natural supplement	NEN 5916
Shape of aggregates		critical shape recommended	
flat pieces	m/m	< 40%	NEN 5935
supplement with round surface		limited % for use in concrete for roads and hardening	NEN 6240
shell extent	m/m	in coarse supplements percentage carbonates < 10% in fine supplements carbonates < 25%	NEN 5922
very fine material	m/m	aggregate group O-l mm: < 10% aggregate group O-2 and O-4 mm : < 4,0% coarse : < 3,0 %	NEN 5917
Physical properties and requirements			
Compound of aggregates	m/m/	recycled concrete aggregate: concrete percentage > 90 %, LA-value < 40 recycled mixed aggregates: concrete percentage > 50 %, LA value < 50	NEN-EN 1079-2/ visual
other not stony elements	V/V	5.4.2.1. bitumen, rubber, metals, glass, etc. <1,0 %	NEN 5942
Chemical requirements			
Chlorides	m/m	aggregate group O-4 mm; > 4 mm unreinforced : < 1 ,0%; < 1 .O % reinforced: ,0,1%, < 0,05% prestressed: < 0,03 %; < 0,015 %	NEN 5921
Sulphates	m/m	< 1,0 %	NEN 5930
total sulphur compounds	m/m	< 1,0 % < **2** % if dry supplement consists of slag	NEN 5936
spot causing iron and vanadium compounds		spot index may not become more then **20**	NEN 5923
fine organic material	**-**	discoloration not darker then standard picture A, or not satisfy standard picture B	NEN 5919 NEN 5920
soft components	m/m	< 0,5 **%**	NEN 5918
light material	m/m	< 0,1 %	NEN 5933

1.4 Environmental requirements

The environmental legislation sets requirements to maximum permissible percentages of organic contamination and leaching of inorganic contamination. Based on the possibility that a requirement (=testing value) will be violated, the products are divided into classes. These classes vary in possibilities that individual measuring values can exceed limit values (class 1 < 10 %, class 2 10 – 50 %, class 3 > 50%). For each class specific basic assumptions are obtaining with reference to the testing of critical components. For recycled masonry aggregates, recycled hydraulic mixed aggregates and crusher sieve sand the in table 2,3 mentioned basic assumptions are applying.

Table 6. Basic assumptions for testing of critical components (production control) category 1 materials according to the building materials decree.

Product	vicinity of application	class	critical components
recycled masonry aggregates	bottom fresh surface water	III	Antimonium Bromide Chloride Sulphate Poly Aromatic Hydrocarbon (10) mineral oil
recycled concrete aggregates	bottom fresh surface water	II	Barium Fluoride mineral oil
recycled mixed aggregates	bottom fresh surface water	II	Barium Molybdenum Fluoride Sulphate Poly Aromatic Hydrocarbon (10) mineral oil
moulded recycled hydraulic mixed aggregates	bottom	III	Bromide chloride Sulphate Poly Aromatic Hydrocarbon (10) mineral oil
unmoulded recycled hydraulic mixed aggregates	bottom	III	Barium Molybdenum Bromide Chloride Fluoride Sulphate Poly Aromatic Hydrocarbon (10)

			mineral oil
recycled crushed sand	bottom fresh surface water	III	Antimonium Fluoride Sulphate Poly Aromatic Hydrocarbon (10) mineral oil
asphalt aggregates as semi-manufactured product for asphalt	bottom	III	Poly Aromatic Hydrocarbon (10)
bounded asphalt aggregate	bottom	III	Poly Aromatic Hydrocarbon (10)

Testing on class division has relation to the last 300.000 ton product. This testing has to be performed once per 100.000 ton production. With this the component with the highest chance of exceeding is the one that will be normative for the class division of the product.

1.5 Frequency of testing

1.5.1 Compilation and emission

In table 7 it is indicated how frequently the products, minimally, have to be controlled, in principle, by the producer on compilation and emission.

Table 7. Frequency of testing / production control

class division of product	production control
class I	minimal 1 x per 15.000 ton
class II	minimal 1 x per 10.000 ton
class III	minimal 1 x per 5.000 ton

Table 8. Frequency verification investigation

national production	verification investigation
< 2 Mton / year	minimal 1 x per 50.000 ton
2 – 6 Mton / year	minimal 1 x per 150.000 ton
≥ 6 Mton / year	minimal 1 x per 300.000 ton

1.6 Adaptation of frequency of testing production control of compilation and emission

Depending on the results of the successive determinations, the minimal frequency of testing for the production control can be adapted. This can be evaluated per component. Herewith one can distinguish between a mitigate, normal and enhanced testing regimen (see table 9).

Table 9. Minimal frequency of testing / production control

class division	production control		
	mitigated regimen	normal regimen	enhanced regimen
class I	minimal 1 x per 25.000 ton	minimal 1 x per 15.000 ton	minimal 1 x per 5.000 ton
class II	minimal 1 x per 15.000 ton	minimal 1 x per 10.000 ton	minimal 1 x per 5.000 ton
class III	minimal 1 x per 10.000 ton	minimal 1 x per 5.000 ton	minimal 1 x per 2.500 ton

1.6.1 Mitigated regimen

If the preceding 10 consecutive determinations under normal regimen are approved and production continuously took place (no stop longer then one week), one can turn to the mitigated testing regimen. If under the mitigated testing regimen the last measured result leads to an exceeding of the testing criterion or after an interruption of the production for longer then one-week, one has to change to an enhanced testing regimen.

1.6.2 Enhanced regimen

If during the five preceding consecutive determinations under normal regimen two determinations are leading to exceeding of the testing criterion, one has to change to an enhanced testing regimen.
If during the enhanced testing regimen the five preceding consecutive determinations have not led to an exceeding of the testing criterion, one can change to a normal testing regimen.

1.6.3 Temporary stop of inspection

If during the five preceding consecutive determinations under enhanced regimen all five determinations have led to an exceeding of the testing criterion, a temporary stop of inspections has to be established and the producer has to take measures in order to improve the quality of the products. After implementing these measures one has to follow the enhanced testing regimen.

1.7 Poly Aromatic Hydrocarbon (10) percentage of the fine fraction of recycled aggregate 0/40

The Poly Aromatic Hydrocarbon (10) percentage of the fine fraction of recycled aggregate 0/40 has to be determined 1 x per 10.000 ton product.

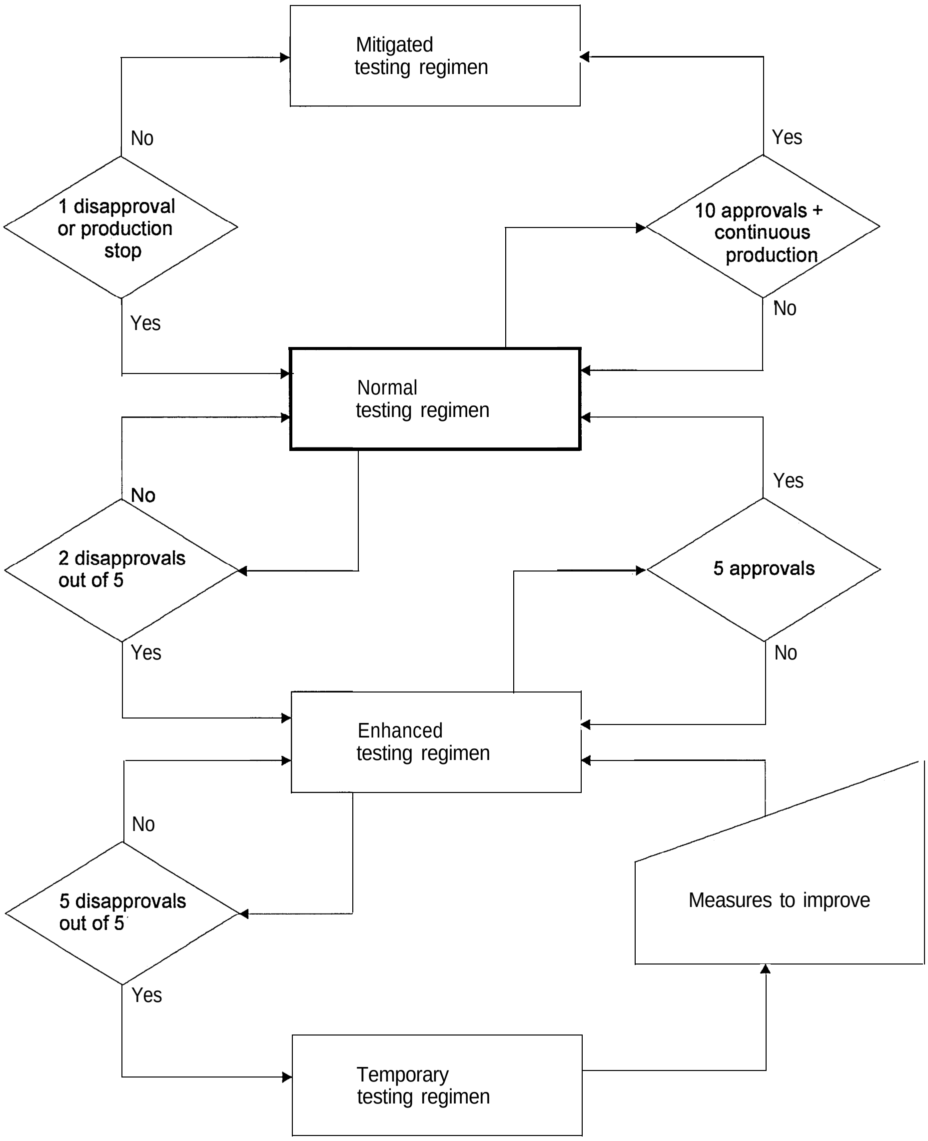

Figure 2. Adaptation of testing regimen

References

1. Hendriks, Ch.F. (1997) *Construction materials and the environment,* Delft University of Technology (in Dutch).
2. *Guidance for quality certification of recycled aggregates BRL 2506* (1997), CROW, Ede (in Dutch)
3. *Building Material Decree,* Ministry of Environment, The Hague (1997) (in Dutch)

Performance Of Concrete With Recycled Aggregates

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ABSTRACT

In the Netherlands, as well as some other European countries, recycled aggregates are applied increasingly. Recycled aggregates are obtained from the processing of stony building and demolition waste. Concrete, containing up to 100% fine and coarse aggregates may be utilised successfully. Significant savings on primary aggregates may be obtained, thereby contributing to closing the concrete life cycle. It is estimated that in Europe alone, about 200-300 million tonnes of building and demolition waste is currently landfilled or applied in road construction. However, recycled aggregates may also be applied very well as coarse aggregate in concrete, thereby upgrading its application.
In this paper, the practical experiences gained with the application of recycled aggregates in concrete in the Netherlands will be highlighted, starting with a brief historical overview of relevant actions taken in the past, and ending with a discussion of future trends.
Introduction of “new” raw materials in the building industry is only possible when there is no discussion on aspects such as the product quality and the ratio between price and performance. Therefore, this paper will give attention to results obtained in the mix-design, strength, durability as well as environmental performance and concrete with recycled aggregates. It will be shown that for the most common ordinary concrete, durability is not a topic for much concern, based on results of tests on chloride-ion ingress and freeze-thaw resistance.

Keywords: chloride ingress, concrete, freeze-thaw, recycled aggregates, specifications, quality control.

1. INTRODUCTION

For millennia, construction and the demolishing of constructions go hand-in-hand. Especially in densely populated countries or regions, an example being the Netherlands, the possibility to recycle stony “waste” materials derived during the process of building, renovation and demolition of structures, has been drawing particular attention since about two decades.
In the Netherlands, almost 15 million tonnes of building and demolition waste’is produced annually; this is equivalent to about 1 tonne per capita. A conservative estimate is thus, that within the EC countries alone approximately 200-300 Mtonnes of this particular kind of waste is produced annually. And just in order to visualise: this is roughly equivalent to an area of $400 km^2$, with a total height of 1 meter, given an average volumic mass of 1.500 kg/m^3.
The major part of building and demolition waste consists of stony components. These components are, upon recycling, generally referred to as recycled aggregates. According to the definition provided in reference [6], a recycled aggregate is a granular material, resulting from an industrial process involving the processing of inorganic materials, previously exclusively used for construction, applied again for construction purposes.
In the Netherlands, the major marked for recycled aggregates is found in relatively low-tech applications such as embankments, road foundations, etcetera. These low-tech applications are faced with an ever-increasing competition with other secondary raw materials, while at the same time demand is decreasing. However, it is very well possible to upgrade the application of recycled aggregates. It then becomes a potential raw material for the large market of “common concrete”, i.e. concrete which does not have to meet the highest standards with respect to workability, flowability, strength and/or durability. In the Netherlands, roughly 80% of the annual concrete production of about 16 million m^3 is used for ordinary concrete in the strength class up to 25MPa, i.e. almost 13 million m^3. The demand for stones and gravel (4 - 32 mm) and sand (0 – 4 mm) for this concrete is respectively about 14 million and 9.5 million tonnes. And although the production rate of this concrete far exceeds the production of recycled aggregate, the application of this material into concrete is - as a concept - interesting, since it contributes to closing the concrete life cycle, thereby contributing to a sustainable society.
So far however, in only few EC-countries a well functioning building and demolition waste recycling industry, actually producing recycled aggregates of sufficient quality, is present. Within Europe, this is particularly the case in the Netherlands.
In the following chapters a historic overview is presented, starting with a discussion of the meaning of the term “sustainable”, the basis of Dutch environmental policy, followed by an overview of Dutch- and EC-policy on recycled aggregates, legislation, standardisation and quality control, resources and types of aggregates produced, processing, practical experiences, ending with a discussion on future trends.

2. SUSTAINABILITY

“Sustainability” is the fundamental topic behind terms like energy conservation, recycling, efficiency improvement, etcetera. Many definitions exist. The Brundtland report of 1987 “Our Common Future”, published by the World Commission on Environmental Development, describes this term by formulating three aims, the first being an economical development, within the prior condition of ecological criteria.
The outlook for next generations (say in about 50 years) is that world population will approximately double, that this world population will have an average level of prosperity which is about 4-8 times higher than the current one, and that at the same time the pressure on the environment should be reduced with a factor of 2-4. For the building industry as a whole, this means that in 50 years we will have to able to build about 15 to 50 times more efficient.

In order to fulfil our common needs for building (housing, infrastructure, etc.), the building industry should contribute by increasing its overall efficiency in terms of raw materials and energy consumption, low emissions into the environment, ease of adaptability of constructions, an optimised durability (design for durability) and, last but not least, the recyclability of constructions (ease of demounting or demolition and recycling, preferably back into its own product chain). It is particularly this latter aspect which is addressed in this paper.

3. DUTCH- AND EC-ENVIRONMENTAL POLICY

As one of the reactions on the Brundtland report the Dutch National Environmental Policy Plan (NMP) was published in 1989. In this document, as well as the later published update of this plan, and in the "National package" on "Sustainable Building - Investigation into the future", intentions and guidelines were formulated with the aim to anchor the concept of sustainability into, amongst others, the Dutch building industry. A few years back this resulted in an "Implementation Plan on Building and Demolition Waste", with the aim to apply 90% of this kind of waste by the year 2000. In this plan, and its subsequent updates, no particular preference for any particular application was formulated. Integral chain management is considered to be one of the central themes needed in order to reach a "sustainable" way of building. Integral chain management may be considered as the closing of a product or material life-cycle is such a way that only a minimised amount of material needs to be landfilled or cornbusted, at the same time maximising product and materials reuse and recycling. Preferably, reuse and recycling should take place into the same application. The effect of integral chain management is considered twofold:

1. Materials recycling. This results in a decrease of emissions into air, water and soil (which would take place as a result of landfilling or combustion), as well as a reduction of the environmental impact related to land filling; and
2. Limited use of primary raw materials. This results in a reduced intervention into (scenic) landscapes and extended exploitation of -essentially finite - natural resources.

Within the Netherlands, a National Council for the Construction Industry has been established in order to provide for a discussion platform between building industry and government bodies.
On a much smaller scale, also an EC-building council has been operating. Both councils merely serve to provide a basis for formulating realistic goals, as well as performance related quality criteria.

4. LEGISLATION, STANDARDIZATION AND QUALITY CONTROL

In order to establish a normally operating market for recycled materials in the building industry, one of the major aspects was the formulation of appropriate guidelines. Since the early eighties several Rilem committees have been working in the field of recycling and reuse of secondary raw materials. Results have been presented at the conference proceedings of Rotterdam (1985), Tokyo (1989) and Odense (1993; 4). As a result, a Rilem recommendation was prepared with respect to the applications of recycled aggregates in concrete. This Rilem specification was based on experience obtained since the early eighties in The Netherlands, Denmark and Belgium. Since only few countries have substantial practical experience with the use of recycled aggregates in concrete, only few EC countries developed standards and regulations in this field.
At the same time, two CEN committees were already active in fields which could influence the use of recycled aggregates: CEN/ TC 154 "Aggregates for unbound and hydraulically bound materials for Civil engineering work and road construction" and several task groups within CEN/TC 227, focussing on materials for road construction.
A related, but important discussion was taking place within CEN/TC 229 "Characterisation of Waste".

In 1994 the CEN/TC 154 "ad-hoc group on recycled aggregates" was founded; prime task of this group was to advice TC 154 and its subcommittees on specification requirements and any additional tests required for recycled aggregates. The British Building Research Establishment handles the secretary tasks of this ad-hoc group. This resulted among others to a draft proposal for materials specification for unbound, hydraulically bound and bituminous bound recycled aggregates in 1996 [6].

On a national scale a division should be made between standardisation on the one hand, and legislation on the other hand. The process of national standardisation has been stimulated by the publication of the already mentioned Rilem recommendation. Since a couple of years, Dutch national standards (valid up to concrete with a compressive strength of about 65 MPa) allow for a replacement of 20% (m/m) of natural primary aggregates by either mixed recycled aggregate or concrete recycled aggregates, without the need for additional performance based tests. Mixed recycled aggregates are aggregates which have to contain at least 50% (m/m) of recycled concrete aggregate (and less than 50% (m/m) of recycled masonry aggregate); they should also fulfil other criteria, adressed later. In the recently published "National package for sustainable building in the Netherlands" the suggested standard for concrete was indeed to replace 20% of the primary coarse aggregates (4 – 32 mm), by secondary ones. Currently, there is debate on this 20% limit, since the majority of concrete produced may contain significantly higher amounts [1].

Natural aggregate replacement is allowed, provided legislative requirements are fulfilled. In the Netherlands, diffusion-leaching tests are considered appropriate to monitor this. By January 1999, concrete containing secondary materials, applied outdoors, will have to fulfil to limit values regarding the imission of specific elements into the soil and surface water (which differs from the emission from a building product), specified in the Dutch Building Products Directive. Starting point is the concept that only an increase of specified (an)organic elements by 1% over a period of 100 years is considered to be acceptable. This imission is calculated by taking into account the leaching characteristics of a variety of elements as well as the specific application. For indoor applications, legislation addressing radon emanation is currently in study [l].

Key quality control criteria for recycled aggregates used in concrete include of course grain size distribution, grain shape, the fines content, specific mass, chloride and sulphate content, alkali-silica reactive material (glass), organic components influencing setting and hardening time and "soft' components, such as plastics and wood. Essentially, specifications do not differ much from the specifications for natural aggregates. A summary is provided in table 1.

In the Netherlands, the producers of recycled aggregate carry out quality control; both recycled concrete- as well as recycled mixed aggregates are sold with quality certificates. Periodically, certification institutes carry out audits, thereby providing an external quality control assurance.

5. RESOURCES AND AVAILABLE TYPES OF AGGREGATES

In the Netherlands, each year about 120 Mtonnes of raw materials are used in the building industry; 85% of this quantity is actually produced in the Netherlands. As already stated, the amount of building and demolition waste is currently estimated at about 15 Mtonnes per year. Of these 15 Mtonne, 11 Mtonne is recycled, of which a majority of about 80% in "on the ground" applications; only 20% is applied in "above ground" applications.

In 1996 the total installed recycling capacity was about 16.3 Mtonnes. Total production in 1996 was less: 10.9 Mtonnes. 10.4 Mtonnes were actually applied. About 68 percent of it originated from demolishing operations, other sources being waste produced at large infrastructural projects, such as road construction (15 %) and building waste sorting installations (5%). Approximately 9% of it was produced at building sites, the remaining 3% from other sources.

Several qualities of recycled aggregates are currently available in the Netherlands. They are summarised in table 2.

Table 1. Specifications for recycled aggregates.

description	specification			standard
grain size distribution	sieve	percentage on sieve (v/v)		NEN 5916
		4/16	4/32	
	C63			
	C45		0	
	c31.5		o-5	
	C22.4	0		
	CI6	O-IO	30-70	
	C11.2			
	C8	30-70		
	C5.6			
	c4	85-I 00	85-100	
	2mm	95-100	95-I 00	
grain shape	max. 35% (m/m)			NEN 5935
very fine materials	max. 3% (m/m) < 63 μm			NEN 5917
composition	Specific mass: recycled concrete aggregate: min. 90% (m/m) > 2100 g/m³ recycled mixed aggregate: min. 50% (m/m) LA-value: recycled concrete aggregate: < 50 (% m/m) recycled mixed aggregate: < 40 (% m/m) Non-stony components: max. 1.0 % (m/m)			NEN 5942 ASTM Cl31 NEN 5933 NEN 5942
chloride content	Recycled concrete aggregate: max. 0.015 % (m/m) recycled mixed aggregate: max. 0.05% (m/m)			NEN 5921 (method "A")
sulphate content	acid dissolved sulphate (as SO_3): max. 1.0 % (m/m) total sulphur compounds (as SO_3): max. 1 .O % (m/m)			NEN 5930 NEN 5936
alkali-silica reactive material	may not be present according to standard			NEN 5925
organic components	no significant darkening according to standard			NEN 5919
setting time	no deviation > +/- 25% of standard without recycled aggregates			NEN-EN 196-3
soft components	less than 0.5 % (m/m) may be crushed by hand			NEN 5918

Table 2. Types of recycled aggregates produced in the Netherlands (1996; [I])

type of recycled aggregate	Mtonne/year (1996)
recycled concrete aggregate	1 .0 (+ 0.07 applied in concrete)
recycled masonry aggregate	0.9
recycled mixed aggregates	5.3 (+ 0.11 applied in concrete)
hydraulic aggregates (Korrelmix ®)	0.9
total	8,1 (+ 0.18 applied in concrete)

As can be seen from table 2, about 98% of these recycled aggregates are not applied as secondary raw material in concrete. However, the potential is clearly very high, even when it is considered that recycled masonry aggregates and hydraulic granulates as such can not be applied because of their too low specific mass and friable nature.

New developments include the production of secondary sand (0/4 mm) of various sources. Such sources include sand which comes available at the concrete crushing plant, sand which comes available from sieving operations at crushing plants, sand which originates from cleaned sandy soils and sand which comes available during river dredging operations. The current amounts produced are however small compared to recycled aggregates. Potentially, some 2 Mtonne may be produced of sufficient quality.

6. PROCESSING

Essentially, the processing of building and demolition waste does not differ from the processing of natural aggregates. In order to be economically feasible, plant size ranges typically between 100 and 250 ktonne. Important is that the demolition waste is separated as early as possible in the recycling chain; this should be achieved preferably at the demolition site, but it may also take place in so-called sorting centres.
Separation generally starts with a crushing action. Further sorting may be carried out by sieving, windsifting to separate light materials, a magnetic sorting to separate iron-parts and sieving. Especially when high quality granulates are needed, the material is subjected to a washing step. Disadvantage of washing operation is that in the end usually a polluted sludge remains, which has to be disposed of, at relatively high costs. Debate is currently going on to reduce these costs significantly, since it poses a significant burden on potential high quality applications, such as concrete.

7. PRACTICAL EXPERIENCES

7.1 Availability and price

Although in principle capacity should be sufficient, the market for low quality applications is still very large. Generally, recycled aggregates for concrete are produced on demand. Recycled concrete aggregate is rather difficult to obtain; because of the difficult applicability of recycled masonry aggregates, recycled mixed aggregate is the main product. Prices are similar to natural aggregates.

7.2 Replacement level of recycled aggregates in concrete

For over 15 years demonstration projects have been carried out in the Netherlands. Concretes with varying levels and types of recycled aggregates have been produced. A recent survey confirms that a replacement level of 20% (v/v) of recycled concrete- or mixed aggregates, for common strength classes such as B15 or B25, and likely up to B35, is very well possible without any performance loss [3;4].
Concretes containing significantly higher amounts of recycled aggregates (up to 100% replacement) may also be produced. Currently, in a housing project near Delft 100% mixed aggregates are applied in almost all precast concrete elements used (walls, floors, and foundations). A compressive strength of about 45 MPa was generally reached, exceeding specifications. Furthermore, an increase in noise reduction compared with traditional concrete was noted, apparently due to the use of the more porous mixed recycled aggregate.

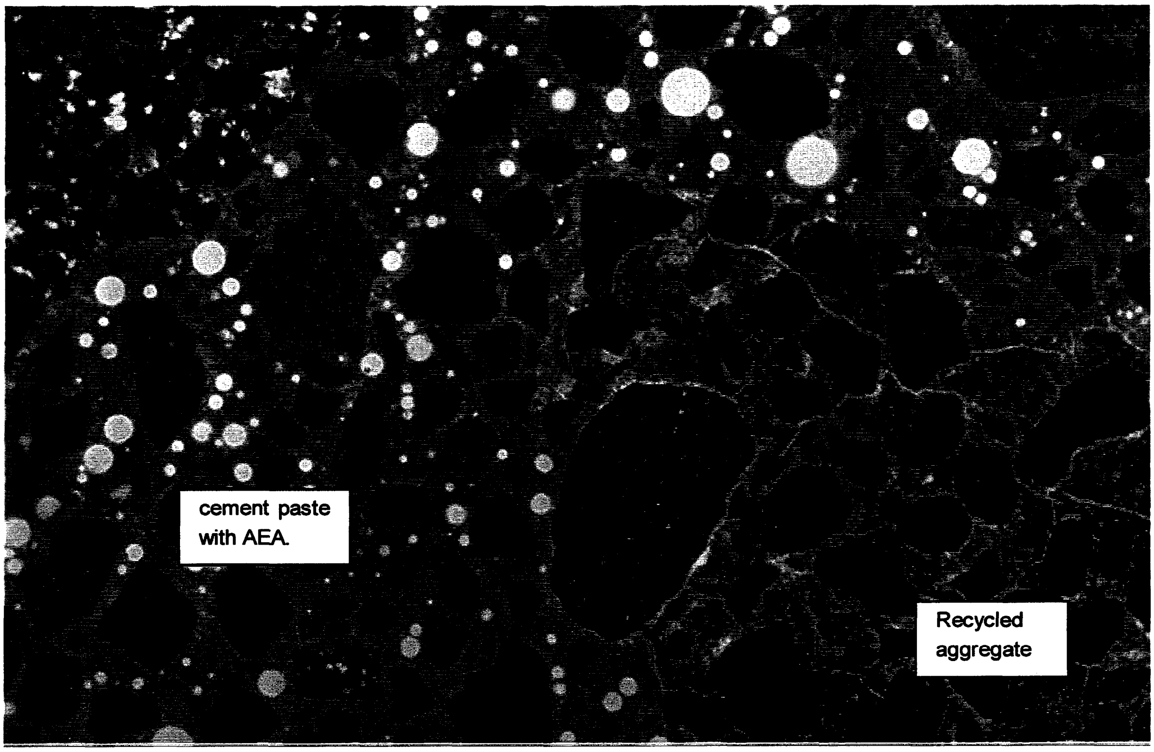
7.3 Mixdesign

In cases of high aggregate replacement levels, care should be taken to analyse the moisture content and adsorption potential of the recycled aggregates, since water demand is usually higher. This is particularly so for aggregates containing masonry or lime-sandstone brick. Three options to overcome this problem exist: the first consist of wetting the recycled aggregates prior to mixing, the second by simply adding more water during mixing, the third by addition of a superplasticiser and/or air entraining agents. Especially this last option is applied successfully in practise. Experiences with replacement of secondary sand 0/4 are still in an embryonic stage. One of the major problems may be, apart from increased water demand plus quality variations within one lot, the hydraulic behaviour, which may cause handling problems in storage bunkers (caking).

7.4 Strength development

Generally, concretes containing up to 20% recycled aggregates do not show a significant strength loss. Higher replacement levels of recycled concrete aggregates also do not seem to be problematic. Due to the hydraulic behaviour of recycled aggregates, as well as their comparatively high surface roughness, good bonds between cement pastes and aggregates exist. An example is shown in figure 1. This micrograph were taken from a (fluorescent) epoxy impregnated thin section.

Figure 1. Microstructure of concrete with recycled mixed aggregate (fluorescent light; 1 cm = 0.3 mm)



7.5 Durability

So far, no damage cases have been reported were the use of recycled aggregates itself was the likely explanation. In practice, no problems with frost-thaw action have occurred, although the porous nature of some recycled aggregates may be a problem in countries with more severe climates, compared to the Netherlands. Air entraining agents may be applied in such cases. In figure 2, some examples of the freeze thaw resistance of concrete with recycled aggregates are shown, based on the RILEM 4 CDC test [2]. Results from chloride penetration tests, according to APM 302, are shown in figure 3. In this test concrete is subjected to a highly saturated chloride solution; after 35 days the relative chloride ingress is analysed. It is an accelerated test. The composition of the concrete used in these tests is summarised in table 3. The water-cement ratio was 0.45. In all cases a superplasticiser was applied, within the allowed specifications. The recycled sand- and aggregates were all pre-wetted; the recycled concrete aggregate contained an additional 16 litres (1.45%), the recycled mixed aggregate 4/16 40 litres (3.6%) and the recycled mixed aggregate 4/32 75 litres (6.8%).
From figure 1 it can be seen that the recycled (concrete) aggregate displays a strong bond with the cement paste, as evidenced by a lack of defects at the interface. Generally, concrete aggregates

display micro-cracks, the significance of which is presumed to be little, as there is not interconnected three-dimensional network present.
The freeze-thaw results from figure 2 demonstrate that the saturation percentage above which "damage" may occur starts at a saturation level of about 77% (critical saturation level). Concrete displaying a critical saturation level over 85-90% may generally be considered to be fully frost-thaw resistant, since such high saturation only occur in special applications. Note that no air-entraining agent was present. The concrete with recycled concrete aggregate performed markedly better than the concretes with recycled mixed aggregates. However, all concretes displayed a performance at least equivalent to the reference concrete with natural aggregates.
From figure 3 it is clear that up to a depth of 12 mm the concretes containing recycled aggregates display a somewhat increased level of chloride ingress; thereafter no difference with reference concrete could be noted. The well-known fact that concrete based on blast furnace slag cement performs better in such tests is also demonstrated.

Table 3. Concrete compositions (all values in kg/m^3)

sample	cement (+ type)	coarse aggregate (+ type)	secondary sand	natural sand
PC	350; CEM I 42.5	1100; Dutch river gravel (4/32)	-	710; riversand
BFSC	350; CEM III 42.5 HL L	1100; Dutch river gravel (4/32)	-	710; riversand
CON32P	350; CEM I 42.5	1100; concrete aggregate (4/32)	248; sieve sand	364; riversand
MIX32B	350; CEM III 42.5 HL L	1100; mixed aggregate (4/32)	248; sieve sand	364; riversand
MIX32P	350; CEM I 42.5	1100; mixed aggregate (4/32)	248; sieve sand	364; riversand
MIX16P	350; CEM I 42.5	1100; mixed aggregate (4/16)	248; sieve sand	364; riversand

Figure 2. Freeze-thaw resistance of several concretes (indicated is the saturation level above which the dynamic E-modulus drops upon 6 frost-thaw cycles)

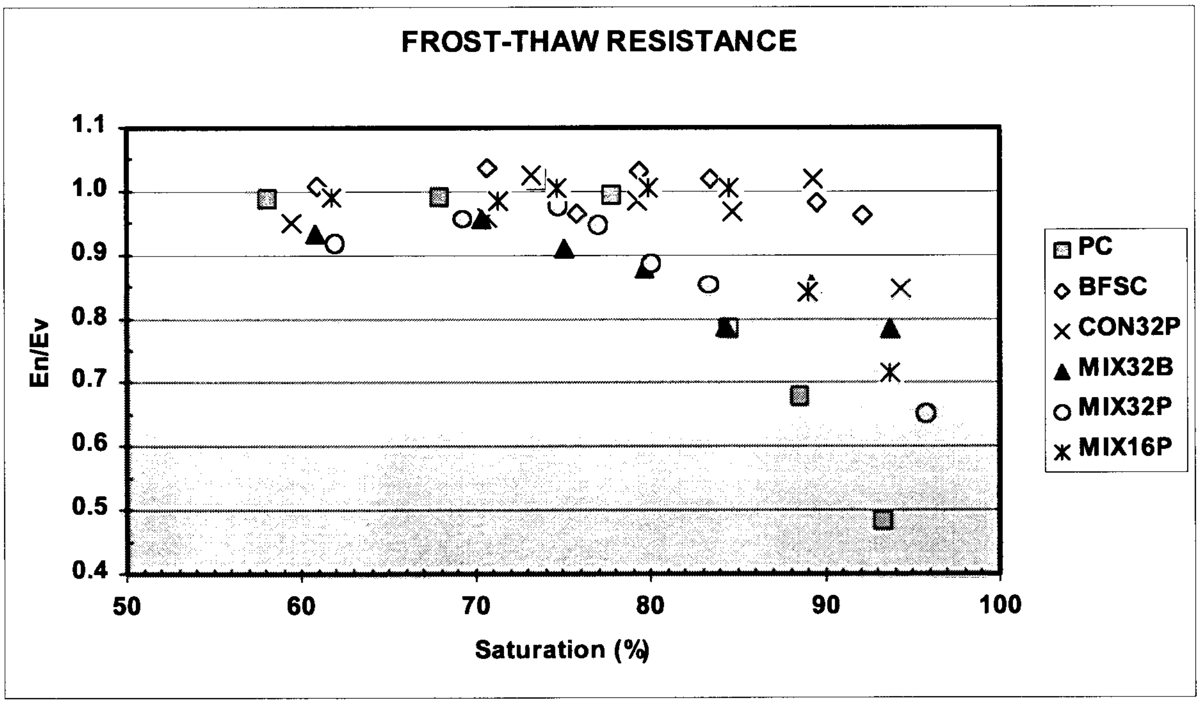
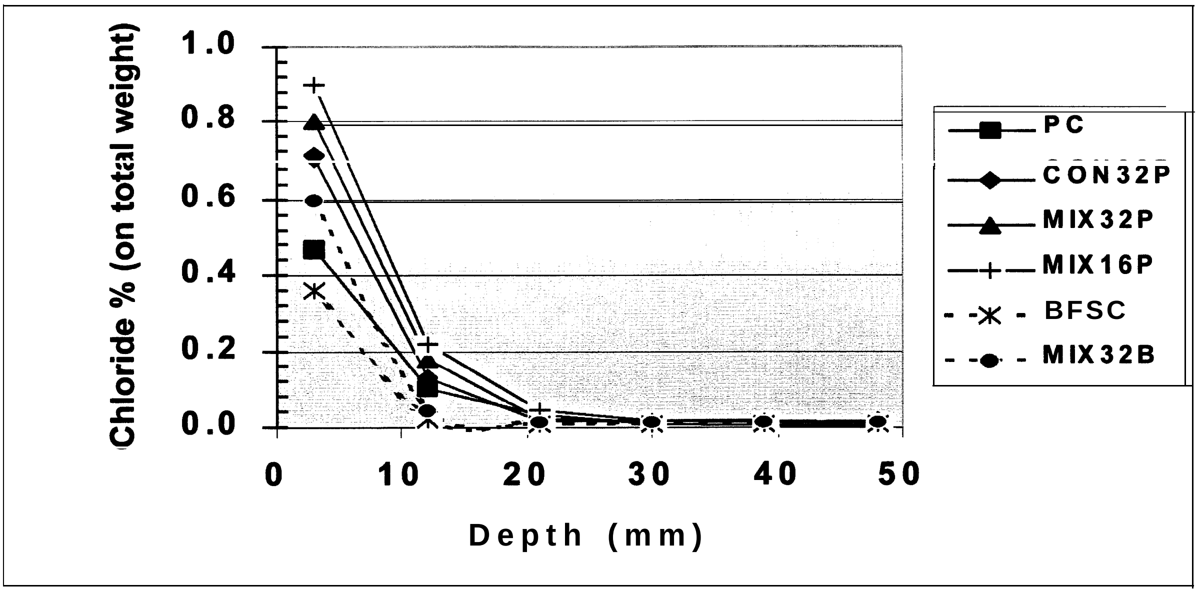


Figure 3. Chloride ingress.



8. CONCLUSIONS AND FUTURE OUTLOOK

Application of recycled aggregates in concrete contributes to closing the concrete life cycle, and reduces the impact on the landscape due to the exploitation and quarrying of natural aggregates.

Recycled aggregates may be applied successfully in concrete. This is especially true for the majority of the concrete market, which consists of relatively low-demanding products. Coarse aggregate replacement levels of 20% to 100% are very well feasible, especially in case of recycled concrete aggregates. The durability of concretes with up to 100% recycled aggregates is, given the concrete quality tested, within range of concrete without recycled aggregates. Both frost-thaw resistance and chloride ingress levels are acceptable for normal use (in the Netherlands). Mix-design should be done with care and experience, since the water demand of notably mixed aggregates is rather high. Pre-wetting is one of the more practical precautions to be taken.

In order to obtain an effective building and demolition recycling industry, the technical- and possible legally required specifications should be made absolutely clear. The best way to obtain good quality aggregates is to work with strict acceptance criteria "at the gate" of a recycling plant. The better the quality and homogeneity of the input, the more easy it is to produce recycled aggregate of high and constant quality. External quality control has proven to be a key element towards a successful market introduction in the Netherlands. The same applies for a clear government commitment.

One of the current discussions in order to stimulate the application of recycled aggregates is to introduce a gate-fee for recycled aggregate, which should counterbalance the residue-dumping costs, which are unavoidable, when the recycled aggregates need to be washed. Currently, the costs of recycled mixed aggregates are approximately 20% less than natural ones, also depending on the building location. Other stimulating actions may consist of prescribing the use of recycled aggegates in buidling specifications. A clear insight in supply and demand of building materials is also needed in order to evaluate results of the stimulating actions taken.

On the long term, it is foreseen that the amount of building and demolition waste will decrease, as a result of renovation, a trend towards more flexible building and an extension of the service life of buildings and structures. From the point of view of integral chain management, application of recycled masonry aggregates in concrete is something that may be of importance when recycling for a second, third or fourth time. The authors are currently addressing this topic [l].

9. REFERENCES

1. Koppen, A.E. (1998) Chain-management of stony building materials (in Dutch), Faculty of Civil Engineering and Geosciences, Materials Science Group, Delft Technical University, The Netherlands, published at: National Building- and Demolition Congress, March 11, 1998.
2. Rilem 4 CDC, Fagerlund, Materials and Structures, Vol. 10, no. 58, p.217-229.
3. CUR report C-125, 1986
4. Demolition and reuse of concrete and masonry, Guidelines: Proceedings of the third international conference on demolition and reuse of concrete and masonry, 24-27 October 1993, Odense, Danmark, Lauritzen, E. K. (Ed.).
5. Stevinreport 22-I-98.01 (in Dutch), February 4th, 1998, Faculty of Civil Engineering, technical university of Delft, Delft, the Netherlands.
6. Pietersen, H.S. Materials specifications for unbound, hydraulically bound and bituminous bound recycled aggregates – a discussion document prepared for the Building research Establishment – Stevinrapport 25. I-96.07, November 1996.

“Green Concrete” is as Simple as ABC

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Abstract:

There is world-wide interest to develop advanced construction materials that are both cost effective and produced with a minimum negative impact on environmental quality. Recently, the Civil Engineering Research Foundation (CERF) organized an international research symposium on “Engineering and Construction for Sustainable Development in the 21st Century. One key element identified was the proper use of by-product materials that can enhance performance, reduce cost and environmental impact.

The interest in using recycled materials as integral components of concrete is well-documented. Recycled concrete, masonry block, brick, recycled post-consumer wood and rubber have been evaluated as “aggregates” and additives for concrete as a construction material. Fly ash, which is a by-product of the coal combustion process, has been used as a filler, cement replacement, and even pelletized as an aggregate for concrete.

ABC™ cement is a newly patented, cement binder, produced in the United States, having a composition of 95 per cent fly ash and 5 percent portland cement. Utilizing this 95 percent by-product, cementitious binder, will provide a “99% plus green concrete construction material when combined with other recycled products used as aggregate. Concrete produced with this “green” binder has been shown to produce excellent short and long-term strengths as well as excellent durability.

Keywords: cement, concrete, construction materials, fly ash, recycled materials.

Introduction:

ABC Cement™ is a patented hydraulic cement system marketed and sold in the United States, and is composed primarily of high-lime, alkali activated, fly ash, mineral additives, retarders, activators, and accelerators. [1] The source of fly ash is subbituminous coal, and is classified by ASTM as Class C. The material can be activated. by water addition alone or by addition of a chemical activator. The Class C fly ash makes up 77- 95 percent by weight of the total cement binder, the remaining part can be slag and/or portland cement. The binder used during this project consisted of 90 percent by-product fly ash, 5 percent portland cement, and 5 chemical additives. The product does not contain any toxic chemicals subject to the reporting requirements of Section 3 13 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA) and RCRA (40 CFR Part 372). [2]

Sustainable Development:

What makes this system so green are the following: The cementitious binder makes maximum use of recycled materials, fly ash from coal burning power plants, and slag from iron and steel making facilities; the material can be used with recycled concrete as coarse aggregate to produce a 99 percent recycled product,, that itself can be later recycled into coarse aggregate; the material appears to have improved durability characteristics that would enable the engineered product produced to endure for a longer period of time; and the material has the potential to reduce the amount of greenhouse gas, carbon dioxide emitted into the atmosphere, and reduce the amount of by-product fly ash that is landfilled.

Reducing the amount of greenhouse gas, carbon dioxide, may not be as obvious as the other three "green" attributes of this system. Worldwide cement production totaled 1.2 billion metric tons in 1992 according to the U. S. Bureau of Mines. [3] This would produce 1.5 billion metric tons of carbon dioxide released into the atmosphere, or 8% of the total carbon dioxide released. [3] The 1.2 billion metric tons of cement would produce approximately 4 billion cubic meters of concrete at a cement content of 300 kg per cu. m. ABC Cement™ binder would require only 60 million tons of portland cement to produce the same amount of concrete at the 300 kg per cu. m. therefore, reducing the amount of carbon dioxide emissions from worldwide portland cement production from 1.5 billion metric tons to 75 million metric tons released. The amount of by-product fly ash utilized worldwide from this endeavor would be a staggering 1 billion metric tons per year. In addition, 40 percent of the 75 million metric tons of carbon dioxide released would, over a period of time, be consumed back to carbonation products, by the 4 billion cu. m. of produced concrete. [5]

Experimental:

Experimental programs were developed by the Army Corps of Engineers at Waterways Experiment Station and Wright Laboratories at Tyndall Air Force Base, FL to develop a property database documenting workability, strength, and durability of ABC Cement™ based mortar and concrete [6 7] The fresh properties measured on the concrete mixtures were slump (ASTM C-143): unit weight (ASTM C- 13 8), air content

(ASTM C-23 1), and time of setting **(ASTM C-403).** Compressive strength testing was also performed on mortar cubes **(ASTM C-109)** at freezing, 0° C., and below freezing temperatures, -18° C. Tests on hardened concrete included compressive strength of cylinders according to **ASTM C-39,** freeze-thaw testing according to **ASTM C-666,** Procedure A, and rapid chloride permeability according to AASHTO **T-277.**

Results:

The results of the hardened concrete and mortar testing are shown in Figures 1-4. Figure **1** illustrates that concrete produced with ABC Cement™ produce compressive strengths at **1, 7,** and 28 days with both gravel and limestone coarse aggregates, comparable to Type III portland cement concrete produced with the same coarse aggregates. The compressive strengths ranged from 24 to 3 **1** MPa at **1** day age and **41** to 55 MPa at 28 days age.

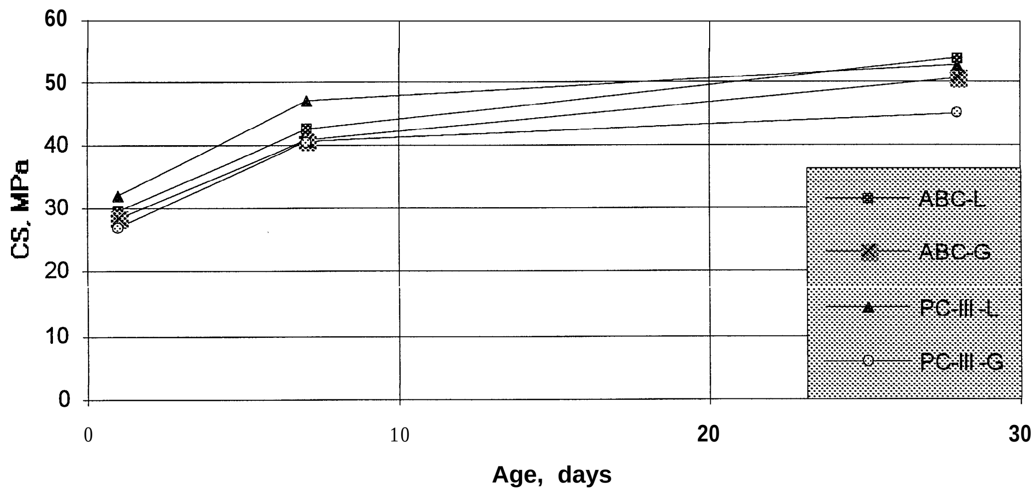

Figure **1.** Compressive Strengths of ABC Cement™ and Type III Cement Concrete

Figure 2 illustrates that concrete produced with ABC Cement™ produce good frost resistance with limestone coarse aggregates, comparable to Type III portland cement concrete produced with the same coarse aggregate. None of the mixtures produced with the natural siliceous river gravel exhibited good frost resistance even with air entrainment. This was not an unexpected result since the river gravel from this source has a history of poor performance in severe freezing-and-thawing exposure.

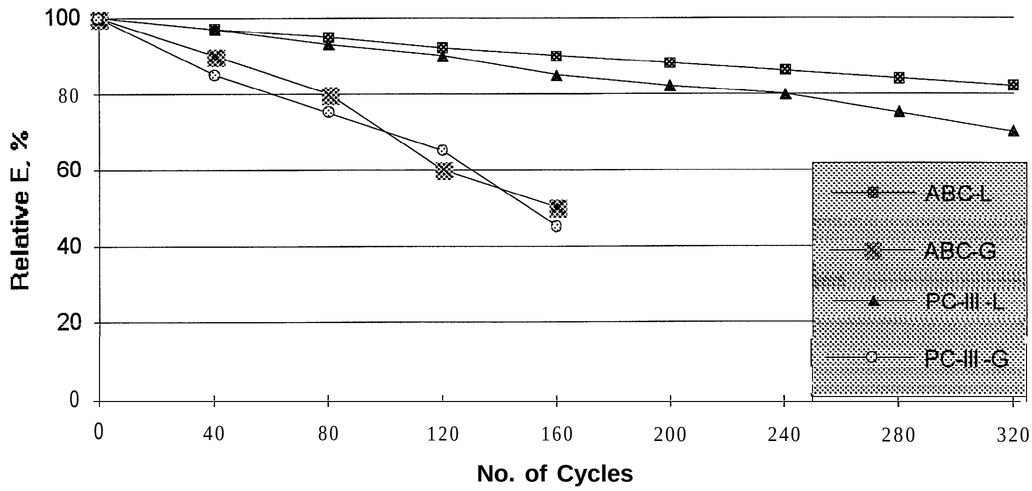

Figure 2. Freeze/Thaw Resistance of ABC Cement™ and Type III Cement Concrete

Concrete produced with the ABC Cement™ exhibited much better resistance to the passage of chloride ions than concrete produced with Type III portland cement. The average charge passed for the ABC Cement™/limestone concrete averaged about 700 coulombs, that corresponds to a very low chloride ion penetrability, and the ABC Cement™/river gravel concrete averaged about 1100 coulombs, that corresponds to a low chloride ion penetrability. Type III portland cement produced with limestone and river gravel coarse aggregates averaged about 2800 and 3000 coulombs of charge passed respectively. Both of which correspond to only a moderate chloride ion penetrability by definition (AASHTO T-277).

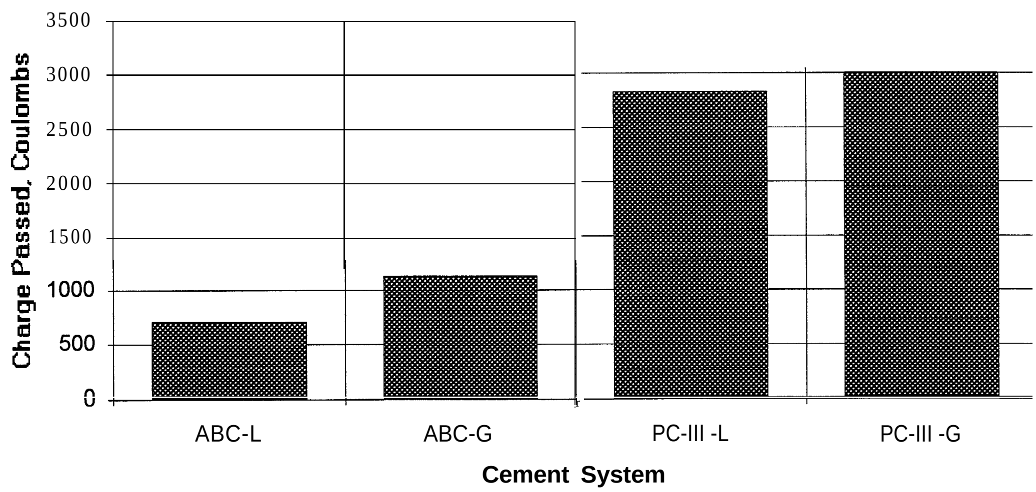

Figure 3. Chloride Permeability of ABC Cement™ and Type III Cement Concrete

Figure 4 illustrates the compressive strength gain of mortar cubes cast and cured at 0” C. and **-18”** C. The three hour strength of ABC Cement™ mortar at 0^o C and **- 18”** C. approached 30 MPa and 20 MPa respectively. The ability of the ABC Cement™ mortar to set and gain strength at these temperature without the use of antifreezing additives was remarkable.

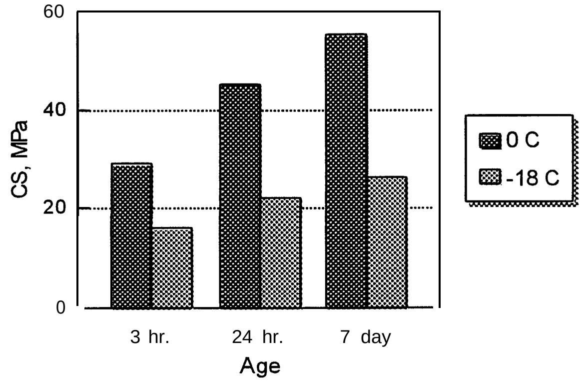

Figure 4. Compressive Strength of ABC Cement™ Mortar at Temperature

Conclusions:

- ABC Cement™ concrete makes maximum use of fly ash and other waste by-product materials.
- ABC Cement™ concrete has fresh concrete properties similar to those of ordinary portland cement concrete.
- ABC Cement™ concrete offers the advantage of improved performance in durability without sacrificing strength performance at early or later ages.
- ABC Cement™ mortar and concrete has the potential to be the construction material of choice in subfreezing conditions.
- ABC Cement™ mortar and concrete has a positive impact on the environment.

Acknowledgments:

The author would like to thank the inventor, W. D. Kirkpatrick for providing the ABC Cement™ material system for testing and evaluation purposes. The author would also like to thank the Army Corps of Engineers at Waterways Experiment Station, Wright Laboratories at Tyndall AFB, and Applied Research Associates, Inc. for providing test data relative to this new product.

References:

1. Kirkpatrick, W. D., and C. W., Blended Hydraulic Cement for Both General and Special Applications, Patent No. 5,374,308, December, 1994.
2. MSDS, ABC Cement, ABC Cement Corporation, 1996.
3. Wilson, Alex, "Cement and Concrete:Environmental Considerations," Environmental Building News, Vol. 2, No. 2, March/April, 1993.
4. Ibid
5. Penttala, Vesa, "Concrete and Sustainable Development," ACI Materials Journal, Vol. 94, No. 5, Sept.-Oct., 1997.
6. "Results of Ash Bonding Chemicals Corporation Cement Tests," letter report by the Concrete Technology division structures laboratory, US Army Engineer Waterways Experiment Station, 1994, in reference to Federal Highway Administration Form DOT F 2300.1 agreement No. DTFH61-94-Y-00070.
7. Dass, S. M., "Laboratory Evaluation of an Alkali-Activated Fly Ash Cement for Airfield Pavement Repair," Final Report, WL/FIVCO, Tyndall AFB, FL, Sept., 1996.

Methodology and experimental programme to evaluate building components service life

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Abstract
In the report we present a method to evaluate the service life of building materials and components, to support decision in design for durability and for a sustainable development.
The evaluation method starts from the concept of durability as the ability of building components to maintain performances and related functional characteristics over a specified limit during service life.
Then the method implies the functional analysis of building components, which let's know, for each material of the component, the functional characteristics that permit to develop the functions directly related to performances and to requirements.
The adopted functional analysis is described in the paper: "Functional analysis as a method to design new building components within a policy of a sustainable construction". The proposed method develops into three phases of analysis.
In the first phase one defines the list of significant agents, one gets from scientific documentation the information on the effects on the materials caused by the agents, and elaborates models to evaluate the "material sensitivity". The second phase, in co-operation with geom. M.Melzi and developed at Istituto Cantonale Tecnico Sperimentale della Scuola d'Ingegneria del Cantone Ticino (Switzerland), with Dr. A.Jornet and Dr. T.Teruzzi, consists of laboratory accelerated ageing tests on material specimens and building components. Characterisation testing will be executed before beginning ageing tests and then repeated periodically during ageing cycles to measure functional characteristics decay until the durability limit, which defines the end of service life. In the third phase one will elaborate the obtained experimental data, to support and conclude the initial methodology, leading to a quantitative evaluation of service life of building components. The information obtained by this method, will represent also a useful input for design and for maintenance management. Once defined the functional model which controls the performances behaviour, building designer will analyse different object models and will choose the optimised ones, from the point of view of service life, considering the real external site agents. The service life evaluation method permits then to choose solutions that will guarantee correct performance levels during predicted service life, and then contributes to optimise natural resources utilisation towards a sustainable development.
Key words : sustainable construction, building components, durability test, service life, maintainability

1 Introduction

The paper's subject takes place in the general theme of the Symposium "Material and technologies for sustainable construction" and, in particular, in the theme "Performance, durability and service life". The problem's solution of the sustainable development in building sector passes through the individuation of the priorities in the choice of the materials to be used in the design and the production of building components. The choice of these materials must take into account their compatibility with the global equilibrium of use of natural resources. Therefore only the materials of which this compatibility is recognised must be used, i.e. those materials which minimise the intrinsic energetic waste of the involved raw materials, the energetic waste due to the transformation into building materials, the waste implied by an eventual recycling to reduce the environmental impact. Within some years at DISET, Politecnico di Milano, it has been developed research work, co-ordinated by prof. P.N. Maggi, about setting up of evaluation methods for the three components of building components technological quality: zero time quality (characteristic quality)' quality during service life (durability) and maintenance quality (maintainability). This paper, related with other papers titled: "Functional analysis as a method to design new building components" and "Experimental programme to evaluate building components service life: an application", reports a method for the evaluation of building components service life.

2 Evaluation method for the sensitivity of building materials and components

The research aims at defining an evaluation method for service life of building components, within a particular class of building components. If exhaustive experimental information would be available, one could estimate building components durability, as the time of service life, after which performance levels decay under specified acceptability thresholds. Actually the lack of experimental information led us first to consider qualitative evaluations, about trends of "effect indicators": so in the first research phase we elaborated a method for the evaluation of durability, based on sensitivity to actions of building materials and components, constituting a catalogue of technical solutions; the component sensitivity is calculated on an absolute dimensionless scale, from the analysis of degradation effects reported by scientific and technical documentation. In the second experimental phase of the research we turned to evaluate the decay of functional characteristics of building components, during laboratory accelerated and outdoor natural ageing tests. To demonstrate the applicability of these durability evaluations we chose a catalogue of technical solutions of "Not-bearing external walls", while the methods may be applied to each class of building components [1]. We consider a "technical solution" as a complex product, composed by elementary products, (let's call them simply "products"), which can be materials, semi-manufactured or elements, at different technological complexity. Then for the sensitivity evaluation method, we consider the available experimental information on durability of such products constituting each technical solution, regarding agents and actions, which may cause degradation. The considered agents have been chosen among all natural and artificial agents [2], significant for the whole building, as the ones which may really stress the specific class of building components, considering external and internal surface exposure. An action is defined as the expression of mediation between one or more agents and the consequent effects: the action is taken into account when it's demonstrated, by technical scientific documentation, to cause some irreversible effect and then the degradation of the products; besides the intensity of significant actions must be comparable to building context. The parameter on which we evaluate product sensitivity to the action is the "effect indicator" defined as the characteristic that consents to measure the effect in testing, and then represents the effect in a synthetic way. Then starting from pertinent information, found in technical scientific documentation, about products durability regarding each action, we elaborate a method for the evaluation of product sensitivity parameters, based on the analysis of each final irreversible effect. The "product sensitivity to an action" , is defined as a function of the following parameters regarding each final effect: the mean time trend of effect (represented and measured by its indicator), the effect surface frequency, the effect depth progression, and the effect time trend regularity. So the "product sensitivity to an action" S_A, is calculated as the mean value of sensitivity evaluation on each final effect caused by this action:

$$S_a = \sum_{e=1}^{E} \frac{F_e \cdot P_e \cdot (T_e + I_e)}{E}$$

where:

E	is the number of final effects *"e"* significant to the action A
F_e	is the effect surface frequency parameter
P_e	is the effect depth progression parameter
T_e	is the effect mean time trend parameter
I_e	is the effect time trend regularity parameter

The mean time trend parameter is evaluated through four classes of increasing risk for the product due to the effect (see Figure 1).

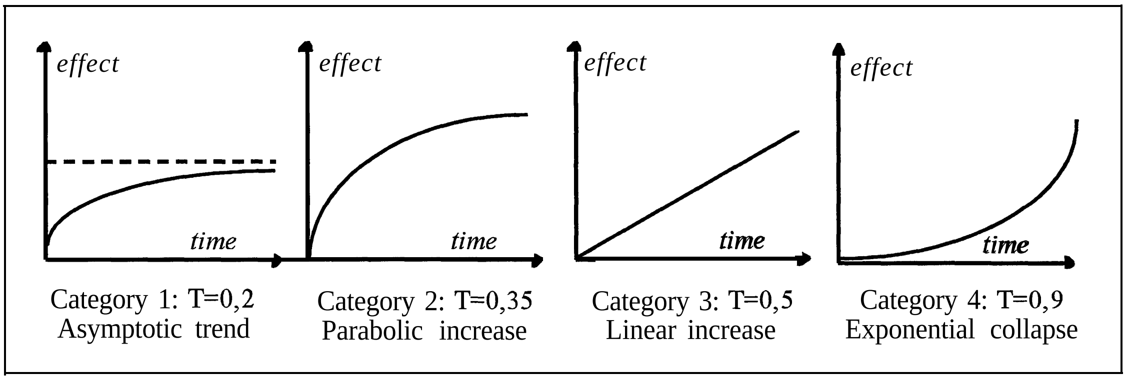

Figure **1.** Evaluation categories for the effect mean time trend parameter "T"

When the effect time trend has some significant irregularities, as fast trend variations or time steps the parameter of mean time trend is corrected by a term "I" called the effect time trend regularity parameter (see Figure 2); this has a positive value +O. **1** when the effect trend has fast worsening, corresponding to material crack or leaks, or it has a negative value -0.1 when the effect trend has some improvement.

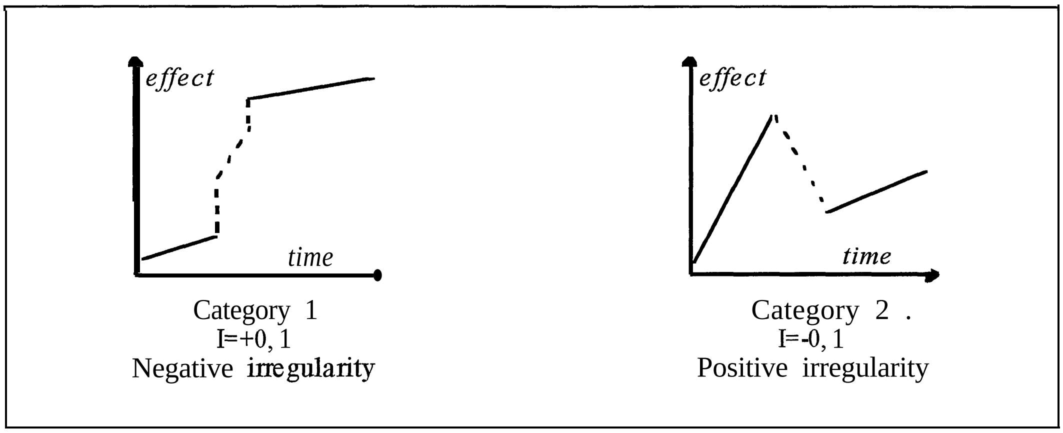

Figure 2. Evaluation categories for the effect time trend regularity parameter "I"

Besides these evaluations on time trend of effect the other parameters evaluate the space distribution of effect; the effect surface frequency parameter "F" (see Table 1) and the effect depth progression parameter "P" (see Table 2).

Effect surface frequency	**category**	**effect surface frequency parameter F**
Localised	1	0.8
Increasing frequency, from localised to uniform	2	0.9
Uniform with different decay start-up points	3	0.95
Uniformly distributed	4	1

Table 1. Evaluation categories for the effect surface frequency parameter "F"

effect depth progression	**category**	**effect depth progression parameter P**
Only surface effect	1	0.8
Depth progression effect	2	1

Table 2. Evaluation categories for the effect depth progression parameter "P"

After setting up the method to evaluate products sensitivity the research work was focused at he experimental validation of such method and in obtaining quantitative data about building components service life. The durability of a technical solution may be defined as the capacity to maintain substantially the initial performances during time. As the functional characteristics of the products in a technical solution are the vectors for the fulfilment of basic functions, related to requirements and performances, we may say that the performance decay of the technical solution depends on the variation of such functional characteristics.

Then the experimental evaluation of durability is based on measurement of time decay of functional characteristics of each product constituting the technical solutions, after laboratory (artificial) and outdoor (natural) ageing. The considered functional characteristics are correlated to technical solutions performances through the functional model, which can be obtained by the functional analysis explained in the report: "Functional analysis as a method to design new building components within a policy of a sustainable construction" presented by Politecnico di Milano, DISET.

3 Experimental programme to evaluate building components service life

3.1 General testing layout

In order to evaluate the durability of building components it was chosen to carry out a series of accelerated ageing tests in laboratory and in outdoor environment simultaneously. The choice to resorting to a double method of evaluation allows to correlate the different scales avoiding to produce unreliable results or, at least, some that are not traceable back to outdoor environmental stresses. As far as the tests in the environment are concerned two contexts with assimilated climate (Milano and Lugano) were chosen but with different levels of pollution. The samples are placed vertically and with an inclination of 45 °. This latter position allows submitting the building components to conditions of greater stresses than the natural ones to which a vertical external wall is subjected. Three types of tests were thus identified: laboratory accelerated test, outdoor accelerated test (45") and outdoor natural ageing test (90°).

3.2 The laboratory test cycle

In order to determinate the length and structure of a complex test cycle, which is able to give back to environmental agent conditions, the outdoor agents that can effect service life of the chosen building components, were first identified. To verify the stressing time and the likely synergies which can develop among the agents both the national standards supports (UN-I and ICITE) and international ones (Swiss standards - SIA 162/1 test n. 7, n.3, n.5 -, ISO/TC 59/SC 3/ N 296, CEN, ASTM E 632, ASTM G 26, DIN 1048 test 5, DIN 52617 -, AFNOR - NF T 30-049) were analysed as well as the documents concerning the testing climatic chamber. The equipment allows to simulate the following environmental conditions:

1. Temperature cycles from +20°C to -20°C in 4'
2. Maximum Temperature +90°C and Minimum Temperature -30°C
3. 15%< Relative Humidity <95%
4. UV Radiation (max 6000W, 90 Klux)
5. Artificial rain

The total cycle (about five and half hours) is divided in four partial cycles interrupted by times of transition (T) necessary to guaranty the passage and the following assessment of the proper condition of every partial cycle.
The test cycle has been so divided:

1. Artificial rain (30'). In this first phase the samples are washed away with water at a temperature of 20°C ±5°C. The climatic chamber is kept at a constant temperature of 20°C ±5°C and at a relative humidity higher than 90%; T_{12}=Transition time: 5'.
2. Freeze (60'). The wet samples are submitted to a temperature of -20°C; T_{23}=Transition time: 8 5 '.
3. Warm and humid condition (60'). The temperature is raised to 55°C with a likely oscillation of ± 2°C whereas the relative humidity must rich values of 95%; T_{34}=Transition time: 5 '.
4. Warm and dry condition with UV exposure (80'). In this last phase there must be a

relative humidity of **20%** in the apparatus with a range of 5% and a planar radiant temperature of 60°C±2°C; T_{41}=Transition time: 5'.

3.3 Laboratory test programme

To carry out the first surveys 28 samples have been prepared (14 protected and 14 unprotected). 8 of these were exposed to environmental stresses (4 in Milan - 2 protected and 2 unprotected - and 4 in Lugano - 2 protected and 2 unprotected) being placed both at 45° and 90°. The first preliminary phase actually consists in verifying if the planned cycle brings to right stressing loads on the samples through the constant measuring of the temperatures and humidity rates, at different depths of the sample, during the progress of the rain and freeeze cycles. Once the preliminary calibrating phase of the cycle is ended the 16 samples, which are pre-set to be introduced in the climatic room (8 protected and 8 unprotected), will be started to be tested.
The test will take 3 month. To reduce the testing time it has been defined a program, which could permit full function of the machine. In the ageing apparatus have been in fact inserted always first samples with higher time of exposition. The program permits to guarantee the same number of cycles and test (destructive and not destructive) for each sample.

3.4 Characterisation tests

All samples are subject to test of functional and dimensional characterisation at the beginning and the end of the pre-defined stressing cycles at different intervals for each sample. There are two types of test: not destructive with a span of a week or two weeks, or destructive with variable span in relation with exposure time (minimum 3 days, maximum 1 month and half). In the first case the measurement is done by observation and is documented by photos (1 photo general and 4 details). In the second case are used specifically instruments and measurements methods related to the characteristics to be measured.

Non Destructive tests		Destructive tests	
Characteristics	**Evaluation methods**	**Characteristics**	**Evaluation methods**
Colour difference	Spectrophotometer	Thickness	Electronic microscope
Specular gloss	Glossmeter	Young's modulus	SIA 162/1 test n.3
Weight	Precision balances	Absolute density	Picnometer
		Capillar absorption	Test as DIN 52617
		Vapour permeability	Test as DIN 52615
		Water permeability	SIA 162/1 test n.5 -DIN 1048 n. .5/ Directive EMPA
		Adhesive power	Tear test
		Specific heat capacity	Mixture method
		Thermal conducibility	Flowmeter method

4. First test samples of a traditional technical solution of external wall

4.1 The technical solutions and the start up of experimental tests.

The experimental tests programme will allow to evaluate the durability of 17 technical solutions of a catalogue of external walls, the most usual in Italian constructions. The technical solution chosen to start the experimental programme is a traditional wall composed by: external perforated bricks, thermal insulated layer, internal hollow bricks, externally coated with plaster and finished with an acrilical plastic coat and water painted. The test will tackle the external coat of the technical solution, so the samples will be only composed by the external coats, starting from the thermal insulating layer. The specimen will have two configurations :

1.NON PROTECTED SPECIMEN		2.PROTECTED SPECIMEN	
9	Perforated brick and mortar concrete	9	Perforated brick and mortar concrete
3 8	Plaster	3 8	Plaster
		8	Plastic coat with acrilical application (RPAC)
		7	Acrilical water painting

The comparison between the results of the non protected specimen and the protected one will show the protective performance of the external coats during the time.

4.2 The project and assembling of the samples

The samples are dimensioned to represent significant sections of the technical solutions and to fit the test chamber (radius: 40 cm ; chamber total dimension: 100x90x90 cm). The resulting sample has the following dimensions: 3 8.5x49x13.5 cm. The sample will be positioned in the test chamber as designed in the figure 3 below ; the four lateral faces will be protected from the water of rain cycle by a metal box, so the water will impact only the face that simulates the external face of the technical solution (Figure 3).

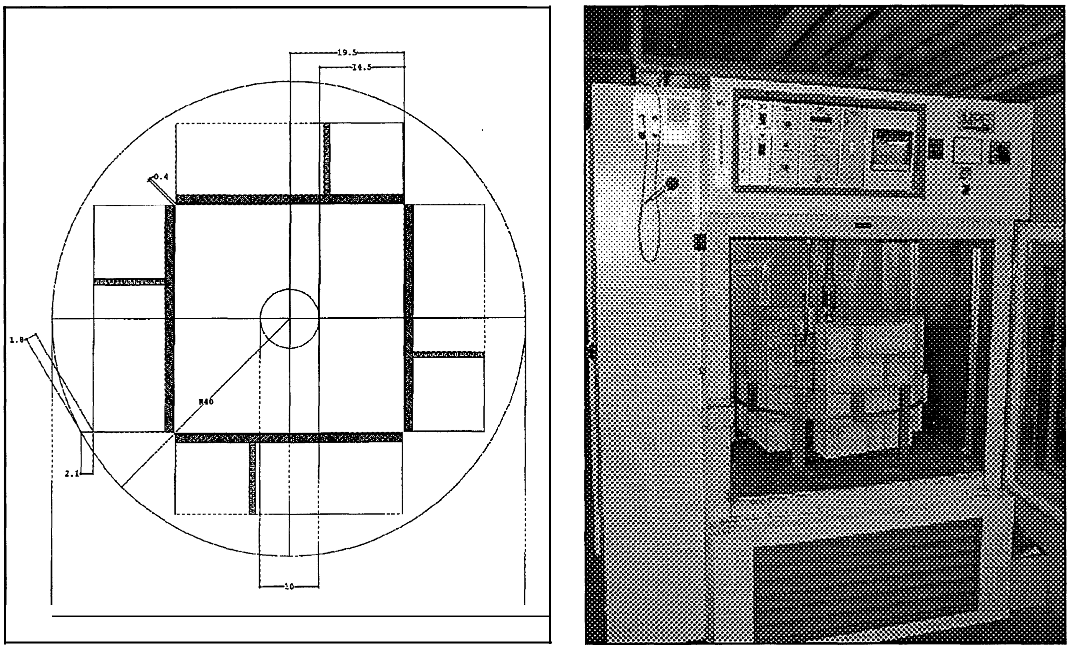

Figure 3 : Samples position in test apparatus.

4.3 The samples assembling

To choose the sand type we have tested some commercial sands normally used in building sites to produce mortars and plasters, and then we have reproduced this curve as sum of selectioned sands in percent.

The composition so defined, in accordance with the commercial and standard grading, will be reproducible as a constant in future tests.

Sieve spread (mm)	**0.063**	**0.125**	**0.25**	**0.5**	1	**2**	**4**	**8**
sands grading %	1.6	10.5	21.1	**39.3**	**58.3**	**82.9**	**99.4**	100

Defined the right sand grading curve, we started with the assembling of the components to produce mortar and plaster.

9	MORTAR	m^3	1
1	Cement Rbk 325	Kg	**450**
7	Sand	Kg	1450
6	Water	Kg	**250**

38	PLASTER	m^3	1
1	Cement Rbk 325	Kg	135
2	hydraulical lime	Kg	315
7	Sand	Kg	1450
6	Water	Kg	**300**

Before their application to produce the samples, some mortar prisms are characterised after a period of 7, **14, 21** days Curing in water positioned in a climatic cell at 20°C.

5 Conclusions

In these days the preliminary experimentation is just to begin: then we will be able to calibrate the experimental programme (see chapter 3); in the next months the testing programme will be executed and the first results will be available: with these data the methodology will be validate (see chapter 2); finally we will start with the experimentation on all the other technical solutions.
The results we will obtain about the building components durability, related with the reliability evaluations, reported in the paper "Method for reliability evaluation of building: application on a set of components" (CIB 1996 - "Applications of the Performance Concept in Building" - Tel Aviv), allow the designer to choose the optimised solution for the specific requirements of his project.
The service life evaluation method permits then to choose solutions that will guarantee correct performance levels during predicted service life, and then contributes to optimise natural resources utilisation towards a sustainable development.

References

1. Daniotti B., Maggi P .N. (1993) *Valutazione della qualità tecnologica caratteristica dei prodotti complessi per l 'edilizia*, Quaderno n° 2 del DISET- Politecnico di Milano, Progetto Leonardo, Ed. Esculapio, Bologna.
2. UNI **8290 p.3.** *Edilizia residenziale. Sistema tecnologico. Analisi degli agenti* . ASTM E **632.** *Developing accelerated tests to aidprediction of the service life of building components and materials.* - BS **7543** *Guide to durability of buildings and building elements, products and components.* Doc. ISO/TC 59/SC 3/ N **296. 199 1.**

Technological complex for utilization of high-calcium ash and slag for Abakan thermal power plant

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Abstract
The Siberian State Academy for Mining and Metallurgy (SSAMM) and Uglestrinproject have developed a project for complex utilization of waste produced by burning brown coals from Kansk-Achinsk Power Complex at the Abakan thermal power plant. The project provides for total utilization of ashes and slags from the thermal power plant for producing finished 'cementless' binder and aggregate, finished 'cementless' fine ash/slag concrete and mortar, precast reinforced concrete structures and small products (silicate brick). Previous investigation of ash and slag from the thermal power plant and concretes on their base was completed in 1995. After grinding and introducing silica time, ash and slag to meet the requirements of State Standard 25818-91, concrete is in accordance with State Standard 26633-91.

The technological complex providing loo-percent utilization of waste products from the TPP includes departments for grinding ash with a storage, for producing sand from slag with a storage, molding with concrete mixers and premises for admixtures. The project has been approved by a nature committee of the Khakass Republic and is in accordance with the ecological standards. The construction of the complex is currently under way.
Keywords: High-calcium fly ash, slag sand, silica fume, cementless binder, technological complex.

1 Introduction

One of the trends towards the utilization of fly ash and slag waste products from thermal power plants, particularly those using brown coals, is the production of construction materials, mortars and concretes for various practical uses.

This work presents the results of a study and a project for a complex utilization of ash and slag from the Abakan thermal power plant, located in the Khakass republic, which is burning brown coals from the Kansk-Achinsk Power Complex. The project provides for the utilization of the total volume of high-calcium ashes and slags from thermal power plants for producing the following materials: finished binder and fine aggregate in the form of slag sand with the particle size of 0 to 5 mm, marketable cementless and lean mortar and concrete as well as precast structures and small concrete products.

Profitability of the project has been achieved through the use of cheap initial materials for the production of the above products.

2 Properties of materials used

2.1 Fly ash

The fly ash from the Abakan thermal power plant was investigated in accordance with two standard documentations:

1. Specification 34-70 10898-88 [1] developed by SibZNIIEP, IKhTTIMS of the Siberian Branch of the Academy of Sciences of the USSR NIIZhB Gosstroy USSR and Moscow Institute of Steel and Alloys;
2. State Standard 25818-91 [2] developed by the leading institutions of Russia with the participation of the first authors.

According to the requirements, physical properties of the ash from Kansk-Achinsk Power Complex were standardized by its fineness and residue on sieve № 008. The data obtained by the authors were compared with the data obtained by SibZNIIEP (Novosibirsk) who investigated ashes from the Kansk-Achinsk Power Complex coals burned at the Novosibirsk power plant and Barnaul thermal power plant №3 [3]. The physical properties determined in accordance with State Standards 3 10.2 - 76 and 3 10.3 - 76 [4,5] are given in Table 1.

Table 1 - Physical Properties of Ash from Abakan Power Plant

Properties	Standards			SibZNIIEP data, Ash from Novosibirsk TPP	SSAMM data, Ash from Abakan TPP
	Specification 34-70.10898		State Standard 25818-91		
	First Grade	Second Grade			
Surface area, no less than, cm^2/g	2800	2000	2500	2996	2358
Residue on sieve №008, no more than,	12.00	15.00	20.00	10.27	7.50

As can be observed from the data given in Table 1, the ash from Abakan thermal power plant can be referred to as a second grade ash due to its fineness, and as a first grade ash due to the residue on the sieve. It exhibited worse properties than the ash from the Novosibirsk power plant №3. For improving its characteristics, raising its chemical activity and eliminating irregular spreading, the ash needs grinding.

Chemical analysis of the ash for oxide and unburnt particles contents made in accordance with State Standard 5382-91 is given in Table 2. The results of the ash analysis can be summarized as follows.

Table 2 - Chemical Analvsis of Ash from Abakan Power Plant

Oxides	Standards			Ash from Novosibirsk Power Plant	Ash from Abakan Power Plant
	Specification 34-70.10898		State Standard 25818-91		
	First Grade	Second Grade			
SiO_2				20.93	39.45
incl. free SiO_2				16.87	24.20
Total CaO		-		31.95	31.20
incl. free CaO	6.00	9.00	5.00	5.51	8.91
MgO	3.00	7.00	5.00	5.96	6.31
Al_2O_3				7.64	7.11
$FeO+Fe_2O_3$				15.37	10.79
MnO				0.44	0.18
P_2O_5		-		0.23	0.06
SO_3	5.00	5.00	3.00	1.87	0.86
TiO_2				0.76	0.90
Na_2O+K_2O	-		1.50	1.80	1.10
Loss on ignition	3.00	5.00	3.00	3.45	1.85
Coefficient of quality, $c_q = \frac{CaO+Al_2O_3+MgO}{SiO_2}$ no less than	1.20	1.00	-	1.47	1.13

1. The coefficient of quality for determining binding properties of the ash [3] indicated that the binding properties of the ash from the Abakan power plant were less (more than 1 .O but less than 1.2) than those of the ash from the Novosibirsk power plant (1.3 times higher).

C_q = (31.20 + 7.11 + 6.317)/39.45 = 44.62 / 39.45 = 1.13

2. Due to calcium oxide (8.91%) and magnesium (6.31%) contents, the ash was referred to as the second grade.
3. Due to the contents of sulfate compounds and loss on ignition (0.86 and 1.85, respectively), the ash was referred to as the first grade.

Though the values of the first two indices were low, the ash had a potential activity reserve. A high percentage of the free silica content of the ash increased its binding properties after its grinding, subsequent treatment with water and heating. Magnesium-containing minerals were also activated after grinding. The data on the SO_3 content and loss on ignition were encouraging in terms of durability of the future concrete and protection of reinforcement from corrosion.

2.2 Granulated slag

The slag from the Abakan thermal power plant was studied in accordance with the requirements of State Standard 26644-U [6]. The glassy slag was separated into two grading fractions: 5 to 10 mm slag rubble (7.5%) and 0.14 to 5 mm slag sand (92.5%). While assessing the slag sand, the characteristics to be considered were bulk density, granulometric composition and chemical analysis. The bulk density determined in compliance with State Standard 9758-86 [7] was 1.58 g/cm^3 (1580kg/m^3).

Grain composition of the slag sand determined in accordance with State Standard 873 5-88 [8] is given in Table 3.

Table 3 - Grading of Slag from Abakan Thermal Power Plant

Sieve size, mm	Residue on Sieve	Cumulative percentage retained, %
5.000	75.0g 75.0%	75.0
2.500	56.2g 56.5%	64.0
1.200	21.5g 21.5%	85.5
0.630	55.0g 5.0%	91.0
0.3 15	50.0g 5.0%	96.0
0.140	30.0g 3.0%	99.0
< 0.140	10.09; 1.0%	100.0

The data on the grain composition indicated that the cumulative percentage retained on the sieve № 063 was 9 1% which was above normal (65%) while the fineness modulus was 4.3 5 which did not meet the requirements of fine aggregates for concrete (2.5 to 3.1 for denser packing). However, grading fraction of 5 to 10 mm revealed microcracks. Therefore, all the slag needed grinding to 0 to 5 mm particle size so it could be used in fine ash-slag concrete containing no natural aggregates. The absolute density of the slag sand was 2150 kg/m^3.

Frost resistance was determined is accordance with State Standard 9758-86 [7]. Before grinding, the frost resistance of slag was equal to 102 cycles of freezing and thawing, whilst after grinding to a particle size of 0 to5 mm, the frost resistance increased to 235 cycles versus 200 cycles according to a State Standard for a dense slag.

Testing for oxide contents was performed in accordance with State Standard 25589-83 [9,10]. The chemical analysis is given in Table 4. The data given in Table 4, showed that the slag sand meets the requirements of State Standards for use in concretes. Resistance of the slag to silicate and ferric decomposition was determined in compliance with State Standard 9758-86 [7]. The weight losses were 6.38 to 6.70% (up to 8% according to State Standard) and 4.42 to 4.60% (up to 5% according to State Standard) for silicate and ferric decomposition, respectively.

Table 4 - Chemical Analvsis of Slag from Abakan Thermal Power Plant

Oxides	Quantities, %	
	State Standard	Actual Sample
Total SiO_2	no standard	56.47
Free SiO_2	no standard	15.51
Total CaO	no standard	29.92
Free CaO	no more than 1%	
Al_2O_3	no standard	8.16
Fe0	no standard	8.20
Fe_2O_3	no standard	1.43
MgO	no standard	3.50
MnO	no standard	0.17
P_2O_5	no standard	0.05
SO_3	no more than 3%	0.11
Loss on ignition		
for dense slags	no standard	
for porous slags	no more than 3%	

2.3 **Silica fume**

Silica fume from the Kuznetsk ferroalloy plant was a fine powder (5 to 6 times finer than cement) of a light grey colour with a fineness of 2200 to 3000 m^2/kg. The data on test results are given in Table 5. X-ray diffraction and DTA showed the presence of silicon oxide mostly in the amorphous from, which increased the hydraulic activity of the silica fume while reacting with lime and binding free lime of a high-calcium ash. The hydraulic activity was assessed by determining the amount of lime absorbed by silica fume from a saturated solution at 85°C. It was 102 mg CaO/g.

Table 5 - Physical Properties and Chemical Analysis of Silica Fume

Physical Test	Results
Fineness	
-passing 45 mm, %	100
– Blaine, m^2/kg	2900
Specific Gravity	2.25
Colour	light grey
Chemical Analysis, %	
SiO_2 total, including	90.11
SiO_2 free	82.00
CaO total	0.71
MgO	0.97
Al_2O_3	1.93
$FeO+Fe_2O_3$	1.82
MnO	0.20
P_2O_5	1.18
Na_2O+K_2O	2.03
Loss on ignition	2.05

3 Optimum mixture proportions

Optimum mixture proportioning of an ash-slag-silica fume blend was obtained on the basis of previous studies [11, 12, 13] and new experiments using a mathematical method of planning [14]. Testing of structures and products (silicate brick in this case) were also made. The test results meet the requirements of up-to-date State Standards for concretes and silicate brick. The optimum mixture proportions for the ash-slag-silica fume blend were the following:

High-Calcium fly ash - 650 - 750 kg/m^3
Silica fume - 70 - 80 kg/m^3
Slag sand - 1000 - 1100 kg/m^3
Water - 180 - 210 kg/m^3
Superplasticizer - 0.7 - 2.0 kg/m^3 (0.1 - 0.3 % by weight of a binder)

As a result of the investigation and tests performed, non-autoclave ash-slag-silica fume brick has been produced with a compressive strength of 12.5 to 15 .0 MPa, frost resistance of 50 to 75 cycles and an average density of 1900 to 1950 kg/m^3 which meets the requirements of State Standard 379-89 "Silicate brick. Specification".

4 Technological scheme for utilization of ash and slag from Abakan thermal power plant

A technological scheme for processing ash and slag and a project of a technological complex for the Abakan thermal power plant have been developed. Collected by electrostatic filters, the high- calcium fly ash with a fineness of 2400 cm^2/g was ground in ball and tube mills to a fineness of 4000 cm^2/g in order to destroy agglomerated particles and fused surface of the ash and thus increase its hydraulic activity. Besides, the grinding stimulated interaction between free calcium oxide and the amorphous microsilica.

Slag from the thermal power plant in a melted state was granulated and then ground by roller crushers to a particle size of 0 to 5 mm. This procedure improved the granulometric composition of the aggregate, eliminated microcracks and stresses in the slag, improved its frost resistance and hence, the properties of the future concretes.

20 to 30 percent of the processed ash and slag is sold to builders while 70 to 80 percent is used for producing various types of concrete and products as well as used in concrete for reconstruction and expansion of the thermal power plant. The schematic diagram of the complex for utilization of fly ash and slag from the thermal power plant is given in Figure 1.

An ash-slag-silica fume blend was made in mixing-crushing runners or fixed-drum concrete mixers using hot water (60-80°C) at 12% relative humidity of the mixture. Brick was produced by dry pressing at 20 to 25 MPa and then was moist-cured in a steam-curing chamber at 95 to 100°C using a 3+10+3 h cycle. The use of 0.1 to 0.3% high-molecular S-3 superplasticizer greatly improved workability of the mixture and increased the strength and durability of the brick. With free CaO contents ranging from 5 to 15 percent the strength characteristics of the ash-slag-silica fume brick did not change greatly.

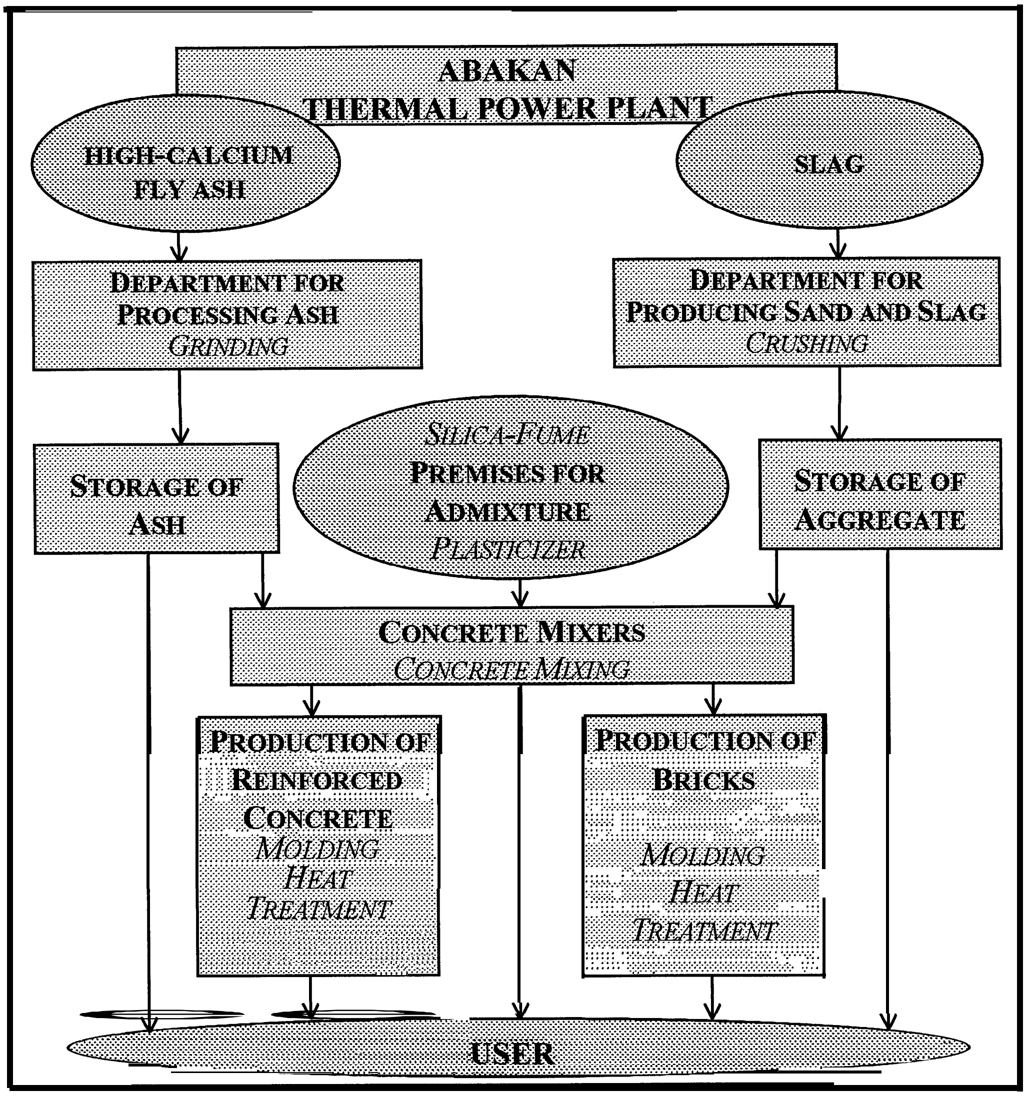

Figure 1 - Schematic diagram of total utilization ash and slag from thermal power plant

5 Technological complex for utilization of waste from power plants

The technological complex provides for the 100 percent utilization of wastes from the Abakan thermal power plant and includes the following facilities:

-the department for grinding ash with a store;

-the molding department with mixers, one of which is designed for the production of a ready-mixed concrete;

-the storage for finished products;

-the storage for admixtures, fuels and lubricants;

-the department for the production of sand from slag with a store for finished products.

6 Conclusions

1. The technology and a “Technological Complex for Utilization of Waste from Power Plants” project for producing ready-mixed concrete, reinforced-concrete structures and ash-slag-silica fume brick have been developed.

2. Organization of the production of ground ash, slag sand, structures and brick at the Abakan thermal power plant permitted the solution of the problem for the total utilization of wastes using steam and energy of the plant which reduced the cost of the products made of the wastes.
3. The cost of the production of a 'cementless' ready-mixed concrete and the ash-slag-silica fume brick are 60 and 65 to 70 % lower-than the production of a cement concrete and silicate brick hardened in an autoclave, respectively.

7 References

1. High-calcium ash from Kansk-Achinsk brown coals as an admixture to concretes and mortars. *Specification* 34-70, 10898-88, Registration № 080/390854, 17.08.88, 13p.
2. Fly ash from thermal power plants used for concretes. *State Standard 25818-91, Specification.* Gosstroy USSR Moscow, 1991, 13p.
3. Ignatova, O.A. (1990) Study of homogenity of high-calcium ash from Kansk-Achinsk coals and development of standard requirements for use in concretes, concretes of the basis of ash and slag from thermal power plants and their complex use in construction, *Proceedings of the International Conference.* Edited by S.I. Pavlenko, V. 1, Novokuznetsk, pp. 145-150.
4. Cements. Methods for determining fineness of grinding. *State Standard 310.2-76*,* Gosstroy USSR Moscow, 1996.
5. Cements. Methods for determining consistency standards, hardening periods and uniformity of spreading. *State Standard 310.3-76*,* Gosstroy USSR Moscow, 1996.
6. Rubble and sand from slags of thermal power plants used for concretes, *State Standard* 26644-85, Gosstroy USSR, Publishing House of Standards, Moscow, 1985.
7. Porous non-organic aggregates for construction works, methods of testing, *State Standard* 9758-86, Gosstroy USSR Publishing House of Standards, Moscow, 1986.
8. Sand for construction works, methods of testing, *State Standard 873588,* Gosstroy USSR Publishing House of Standards, Moscow, 1988.
9. Cements and cement products, methods of testing, *State Standard* **5382-91,** Gosstroy USSR, Publishing House of Standards, Moscow, 199 1.
10. Rubble, gravel and sand for construction works, methods for determining the contents of sulfate compounds, *State Standard* 25589-83, Gosstroy USSR Publishing House of Standards, Moscow, 1983.
11. Pavlenko, S.I. (1992) Fine-grained cementless concrete made with high-calcium fly ash and slag sand from thermal power plants, *Fourth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolons in Concrete, Supplementary Papers,* Istanbul, pp. 749-763, SP
12. Pavlenko, S.I. (1994) Structure formation of slag ash concrete on the basis of high-calcium fly ash and silica fume, *Materials and Structures,* Research and Testing, August, Vol. 27, № 171, Editor M. Brusin, RILEM, printed E & SPON, London, pp.4019407.
13. Pavlenko, S.I. (1997) Cementless binder and silica brick on it. Recovery *Recycling Re-integration, Collected Papers of the R' 97 International Congress,* Geneva, Switzerland, Volume II, Published by EMPA, pp. 11.66-11.70.
14. Voznesensky, V.A. (1974) *Statistical Methods of Planning the Experiment in Technicoeconomical Investigations,* Moscow, Izdatelstvo Statistiki, p. 192.

The effect of panelized single family residential construction on the environment

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Abstract
The construction of single family housing in the U.S. is becoming increasingly industrialized with panelization emerging as the dominant form of industrialization. The question is whether this trend will mean that housing construction, operation, and demolition will have a greater or a reduced impact on the environment.

This paper analyzes the differences between low levels of industrialization, such as site-built wood framing or open wood-frame panels, and higher levels of industrialization, such as closed wood-frame or stressed skin insulating core panels, in terms of material use, waste generation in construction, and energy use in operation. One of the experiments cited compared the energy consumption of six units of housing built using various forms of factory fabrication — open wood-frame panels, closed wood-frame panels, and stressed skin insulating core panels. These tests indicated that the more completely components are factory fabricated, the less energy a house built from these components will consume, resulting in reduced CO_2 emissions from burning fossil fuels. The units built with the more industrializedpanels had a more completely insulated envelope and half the air changes per hour. Another experiment compared conventional onsite construction (wood frame) to stressed skin insulating core panel construction. Stressed skin insulating core panel construction used 5% less total wood and 50% less framing lumber, indicating the consumption of fewer trees. A similar experiment comparing the side-by-side construction of a wood frame house to a panelized house showed that the panelized house construction used less solid sawn lumber and generated less waste onsite. A recent prototype panelized floor/foundation system showed promise as a lower cost alternative to concrete slab construction with its high embodied energy. The on-grade panel floor system has better thermal performance than a typical slab floor, and the panels can be reused upon demolition. These examples show that high levels of industrialization can potentially result in less environmental impact from construction, operation, and demolition.
Keywords: energy, environment, industrialized housing, material use, panels

1 The current state of industrialized housing in the U.S.

Valued at $179 billion in 1994, the housing industry in the United States has an enormous impact on the economy and environment. The 1.6 million housing units constructed in 1995 (about 1 million of which are single-family units) consumed large quantities of raw materials and energy, and represent future demand for resources for operation and demolition [1].

1.1 Types of industrialized housing

Over the past 40 years, the production of houses has increasingly included more industrialized components and processes, ranging from dimensional lumber and prefabricated walls to completely prefabricated homes.

Datacollected on industrialized housing can be divided into four groups (listed here from most to least industrialized): HUD code, modular, panelized, and production-built housing. Houses completely built in the factory are considered to be the most industrialized, and those built primarily on site are the least industrialized. The most industrialized type of housing, HUD code housing, is built to a preemptive national code. A *HUD code* house is a movable or mobile dwelling constructed for year-round living, consisting of one, two or more manufactured units each towed on its own chassis, and connected on site. *Modular* housing is built from self-supporting, three-dimensional house sections intended to be assembled as whole houses. *Panelized* houses are built from manufactured roof, floor and wall panels designed for assembly after delivery to a site. The least industrialized are *production-built* houses, whole houses produced "in situ" using rationalized and integrated management, scheduling, and production processes, as well as factory-made components. Rather than the house constructed in the factory and moved to the site, the building site is the factory — an open-air assembly line of walls, floor or other building components [2].

1.2 Market share of industrialized housing

The last decade of industrialized housing production has shown a growing strength in the *more* industrialized modes of housing. From 1985 to 1995, HUD code, modular, and panel producers captured some of the market share from the less industrialized productionbuilders (including those that use only a few industrialized parts) (Figure 1). Panelized housing (including domes, precuts and log houses) showed the largest increase in market share over this period, expanding from 37% in 1985 to 47% in 1995, and shows promise of increasing growth [3].

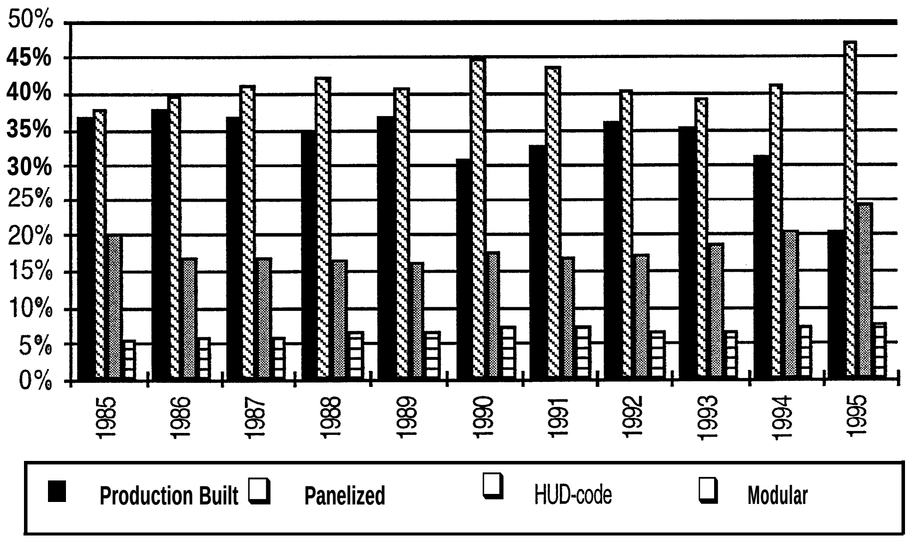

Figure 1: U.S. housing production by market share, 1985–1995 [4]

2 The impact of residential construction on the environment

The cost of housing can be measured in its effects upon the natural environment as well as on the economy. Houses impact air, water, and land quality, require raw material extraction, create waste in construction and demolition, and demand energy in operation. The choice of construction material — wood versus concrete, or engineered wood versus solid sawn lumber — affects the energy used, pollutants emitted, and waste generated during initial fabrication, and represents a potential waste hazard at the end of the building's life.

2.1 Construction material

The construction of houses requires a substantial amount of raw and manufactured materials that affect the natural balance of the environment. In the United States, a typical 194 m^2 (2085 sf) single-family house requires 3 1 m^3 (13,127 board feet) of lumber, 577 m^2 (6212 sf) of sheathing, 12,685 kg (13.97 tons) of concrete, 216 m^2 (2325 sf) of exterior siding, 225 m^2 (2427 sf) of roofing material, 194 m^2 (2085 sf) of flooring material, 284 m^2 (3061 sf) of insulation, 57 1 m^2 (6144 sf) of interior wall material, 257 L (68 gal) paint/coatings, as well as doors and appliances [5]. Since 90% of single-family houses are constructed of wood, housing greatly impacts the quantity and quality of living trees. Single-family homes create the largest single market for solid wood products in the United States. "In 1992 an estimated 41.3 million cubic meters of lumber, 9.0 million cubic meters of structural panels, and 3.0 million cubic meters of nonstructural [panels] were consumed in the construction of just over 1 million houses" [6]. Although-current annual tree growth is greater than harvest, logging practices of road construction and clearcutting lead to erosion, irreplaceable loss of topsoil, and the pollution of rivers and streams [7]. The demand for sustainably harvested wood in the U.S. has led to the growing number of sustainable forests, currently about 3.5 million acres of forest land [8].

The choice of material used in construction affects the degree of environmental impact. For example, when prefabricated panels are utilized as a treated wood foundation for basements, "the use of wood rather than concrete reduces the amount of embodied energy by about 30%" [9]. Concrete requires 1453–1589 kg (3200-3500 pounds) of raw material for 908 kg (one ton) of finished cement, produces CO_2, NO, and S gases, and requires 2344 MJ/m^3 (1,700,000 BTU/yd) of energy [10]. Wood, on the other hand, is a renewable resource, with low embodied energy, and shows promise of sustainable harvesting. Wood uses the least embodied energy of any building element at 2.5 MJ/kg (639 kilowatt hours per ton). (For comparison, brick uses four times this amount, concrete (5x), plastic (6x), glass (14x), steel (24x), and aluminum (126x) [1 1].

While wood has less environmental impact than other materials, using fewer trees and producing less wood waste can further reduce this impact. Engineered lumber consumes fewer trees to fulfil1 the same structural function as solid sawn lumber. Although lumber and timber consume half as much energy (7.38 MJ/kg) as veneer and plywood (14.62 MJ/kg) [12], the manufacture of engineered wood is highly efficient, using wood scraps and sawdust, so it saves trees. One manufacturer uses engineered lumber made from fast-growing trees like aspen or yellow poplar; the technology allows for use of "logs that are not large, strong or straight enough to be of structural value in conventional wood products" [13]. For structural engineered lumber, three-quarters of each tree is used, resulting in less waste than when using solid sawn lumber. Another example is the use of Oriented Strand Board (OSB) sheathing instead of plywood; OSB uses 59% less embodied energy than plywood because it makes better use of wood fibers [14].

2.2 Waste and air pollution

Building houses creates scrap material and other waste products that require time, energy, and means of disposal, whether by recycling or landfill dumping. A typical 186

m^2 (2000 sf) home generates the following construction waste: metals: ***68*** kg (150 lbs); drywall: 908 kg (2000 lbs); solid sawn wood: 726 kg (1600 lbs); vinyl: 68 kg (150 lbs); engineered wood: 635 kg (1400 lbs); masonry: 454 kg (1000 lbs); cardboard: 272 kg (600 lbs); containers (paints, caulks, etc): 23 kg (50 lbs); and 476 kg (1050 lbs) miscellaneous waste. This combined total of 3632 kg (four tons) of construction waste averages about $5 11 paid per house for disposal [15]. Wood products account for 40–50% of the residential construction waste stream.

Residential construction not only has an impact on the environment in terms of raw materials but also because of the transportation of materials to the site. An estimated 20–25% of the total energy for construction is due to transportation, which contributes to global warming via carbon dioxide emissions. One fifth to one quarter of total annual U.S. CO_2 emissions are generated from the manufacturing of buildings [16].

2.3 Energy use in operation

The composition and quality of construction of a house's exterior walls, roof and floors — the building envelope — substantially affects the energy consumption and cost over its lifetime. A Norwegian study found that the "[operational] energy use in buildings during the service life (50 years) accounts for more than 95% of the total energy consumption throughout the life of these houses" [17]. Residential buildings account for about one fifth of the United States' primary energy consumption, with 46% of this energy used primarily for heating and cooling [18]. Since energy use primarily requires burning fossil fuels, a more energy-efficient house is kinder to the environment in the long run. Heating and cooling residences in the U.S. accounts for 2 1% of the total U . S . CO_2 emissions from fossil fuels, producing 268 million metric tons of CO_2 per year as well as other gases detrimental to air quality and the atmosphere [19].

3 Less environmental impact with more highly industrialized panels

The growing use of panels in housing construction implies a varied impact on the environment through material and energy use depending on the type of panel. The panelized housing industry spans the spectrum of levels of industrialization, defined as the degree of completion of a panel when it arrives on the job site. Less industrialized panels need a moderate amount of finish work on the site, and more industrialized panels require less work on site (Figure ***2). Framedpanels,*** either open framed or closed framed, are prefabricated components replicating traditional stick framing and displaying low to moderate levels of industrialization. These panels consist of dimensional wood studs attached to wood sheathing such as Oriented Strand Board (OSB) or plywood. Framed panels carry structural loads through a stud frame as well as the sheathing. Predominantly used are the less industrialized ***open wood-framed panels,*** which are sheathed on the exterior only and completed on site with vapor barriers, interior finishes, and electrical and mechanical systems. More industrialized are the ***closed wood-framed panels***, which are shipped to the site sheathed on both the exterior and interior, and are sometimes pre-wired and plumbed. The most industrialized panels, the ***Stressed Skin Insulating Core panels,*** have a core of expanded polystyrene rigid foam insulation sandwiched between two sheathing layers that carry structural loads. These panels represent a new building component that cannot be fabricated on site, but requires a factory setting for production.

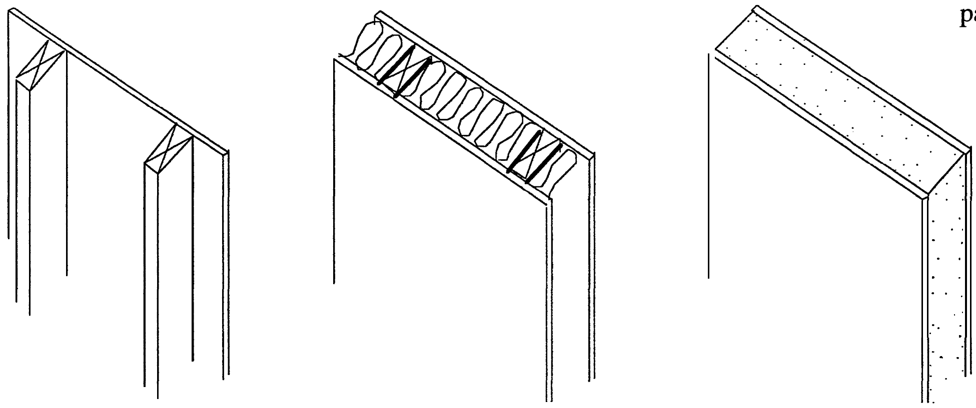

Figure 2: Types of industrialized panels

3.1 Fewer trees consumed with stressed skin paneled housing

Evidence shows that housing built with stressed skin insulating core (SSIC) panels consumes fewer trees compared to housing constructed with less industrialized methods. In an experiment conducted at the University of Oregon, the construction of an SSIC panel demonstration house was compared to that of a reference house of the same design and energy performance, but built with conventional onsite wood frame construction, The SSIC panel house used 5% less total wood, and 50% less framing lumber [20]. In another study, a stressed skin panel house and stick framed house, identical in plan, were constructed in a side-by-side comparison at the 1996 National Association of Home Builders (NAHB) convention. The more industrialized stressed skin panel house consumed the same amount of sheathing material, but 26% less framing lumber (35.6 m^3 or 15,100 board-feet) compared to the traditionally constructed stick frame house (48.1 m^3 or 20,400 board-feet) [21].

Using less framing lumber reduces the total number of trees required for the SSIC house and lessens the impact on the environment. Only 63% of a tree can be manufactured into solid lumber. However, more than 95% of a tree can be utilized when producing composite wood products such as plywood and OSB [22].

3.2 Reduced waste with panel construction

Housing built with panels can reduce the amount of wood waste entering landfills, since panels use primarily OSB and are factory produced, centralizing waste. Composite sheathing plants such as those that produce OSB divert about 8.2 x 10^9 kg (9 million tons) of residual wood from North America's landfills every year [23]. Highly industrialized processes such as panel production benefit from the centralized function and economies of scale of a factory, especially when directing waste. "Materials which are assembled into finished components under factory-controlled conditions usually make more efficient use of resources, and disposal of waste from a factory is more easily controlled" [24]. When waste is centralized and consolidated, it is more likely to be recycled properly instead of buried in a landfill. In NAHB's side-by-side test, the stressed skin panel house produced 76% less waste on site (3 m^3 or 4 yards) than the less industrialized wood-framed house (13 m^3 or 17 yards) [25].

A centralizedproduction scheme also reduces transportation. For example, a stick-built house requires separate transportation of relatively small amounts of drywall, studs, and sheathing. A panel produced in a factory means larger shipments of these items, capitalizing on the economy of scale. The standard 1200 mm x 2400 mm (4'x8') size of panels originated because "the economical transport of a factory-built house suggested the dimensions of a standard trailer truck as a design criterion — the 2400 mm (eight foot) width being particularly crucial" [26].

3.3 Less energy consumed in operating a stressed skin panel house

The more highly industrialized the panel, the better the energy performance of the panel-built house due to the quality of the insulation installation and the thermal performance of the insulation type. A study performed at the University of Oregon compared the thermal performance of six housing units constructed with open wood-framed panels, closed wood-framed panels, and SSIC panels. The units constructed of closed panels (Unit 2, Unit 5, and Unit 6) and the SSIC panels (Unit 1) were more airtight and had fewer thermal defects in wall insulation than the units constructed with the less industrialized open panels (Unit 3 and Unit 4).

Fan depressurization results suggested that the more industrialized panel construction achieved tighter construction resulting in reduced infiltration. The air changes per hour (ACH) measured 0.16 for the SSIC panel unit, 0.27–0.28 for the closed panel units and 0.34-0.39 for the open panel units [27]. Constructed a year later, the Demonstration House (DH) built with SSIC panel floor, walls, and roof showed even tighter construction at a measured 0.09 ACH (Figure 3) [28].

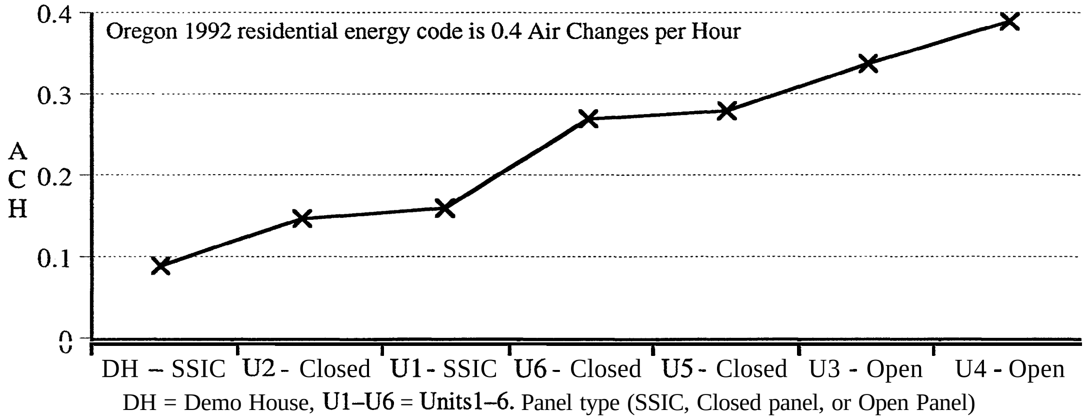

Figure 3: Tighter construction with more highly industrialized panels.

The results from thermographic imaging and coheating tests indicated that a higher level of quality control is achievable in the factory when installing insulation. The infrared imaging detected thermal weak spots caused by missing or poorly installed insulation in the site-installed insulation, predominantly in the open panel units. The open frame and closed frame panel units showed more heat loss through thermal bridging due to studs than the more highly industrialized SSIC panel unit, where the thermally broken splines were only detectable at building corners. Coheating tests indicated that the more industrialized closed panel units had lower overall thermal transmittance (UA) than the open panel units [29]. The 1280 sf SSIC demonstration house had a measured UA value of 133 BTU/h °F compared to 198 BTU/h °F for Unit 3 (800 sf) built with open panels.

Two identical houses were built in Louisville, Kentucky, one constructed of SSIC panels and the other using conventional site-built wood framing. The SSIC panel house outperformed the wood-framed house by 12–19%, mostly due to reduced loss from infiltration and thermal bridging. The air changes per hour (ACH) of the SSIC house were measured at 0.21 compared to 0.4 to 0.7 ACH for the conventional house [30].

4 On-grade floor panel system consumes less energy

The foundation and floor of a typical residence affects the environment through the materials used in the initial construction phase, through its energy performance in operation, and by its disposal at the end of its lifespan. A recent experiment using SSIC panels at the University of Oregon combined floor and foundation to reduce the cost of construction and the amount of concrete used, maintain energy and structural performance in operation, and provide easy dismantling and recycling upon demolition of the structure [31]. The prototype floor/foundation system uses one-sided SSIC panels on a compacted gravel bed, using engineered lumber as the perimeter beam (Figure 4). This floor/foundation system can potentially replace concrete slab floors — which represent 42% of the new single-family residences in the U.S. in 1995 [32] — with materials having lower embodied energy and cost. The on-grade panel floor costs 18% less than an equivalent slab-on-grade foundation and 40% less than a crawl space foundation. Thermal analysis indicates better energy performance than a slab-on-grade floor, with a measured F value of 0.1, compared to 0.5 required by code for a concrete slab. The ease of dismantling the structure also indicates potential in recycling and reuse at the end of its lifecycle.

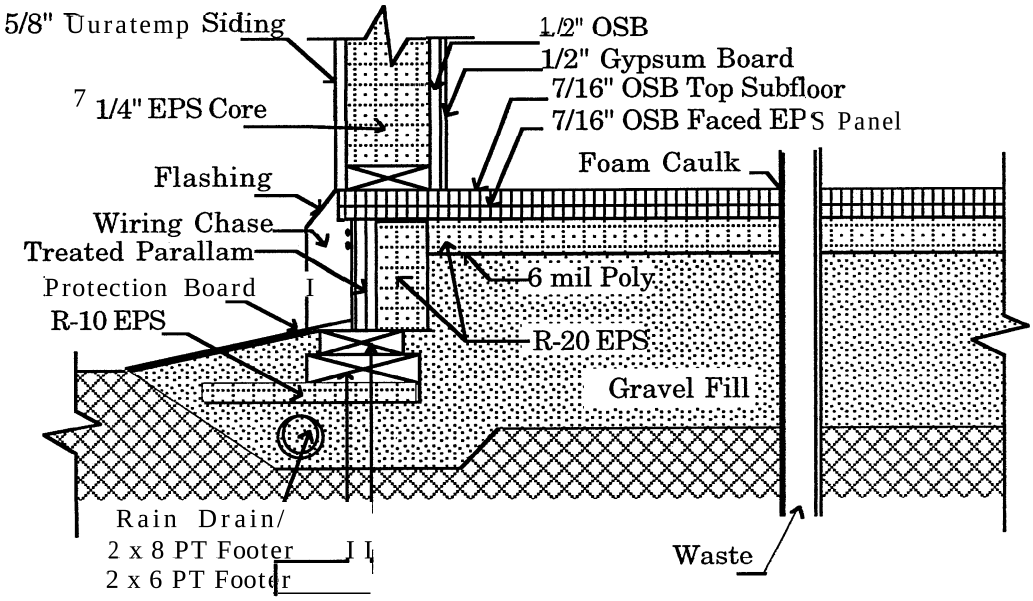

Figure 4: On-grade insulated panel floor system

5. Conclusion

This paper demonstrates the potential of industrialized panel construction in housing in reducing environmental impact by using fewer trees and creating less waste in construction, consuming less energy in operation, and showing greater potential for reuse at the end of a house's service life than conventional stick frame construction.

Many critics contend that industrialization is the antithesis of environmental regard. In residential construction this translates into a movement towards building products that have less processing and use more labor. While this low-tech approach has value it is clear that higher levels of industrialization at least in housing can also lead to reduced environmental impact.

Acknowledgement

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References

1. U.S. Bureau of the Census. (1994-l 995). Construction Reports, Series C-22, Housing Completions and Series C-20, Housing Starts.
2. Brown, G. Z., D. Bjornson, K. Carson, E. Dorsett, J. Kline, and L. Nixt. (1996). *Industrialized Housing* Trends *in the U.S.* (10015/R96-4:db). Center for Housing Innovation, Univ. of Oregon.
3. Morgan, Rick. (1995, November). Lower Manufacturing Costs Will Cause Panel Sales to Soar. *Building Systems Magazine . 14.*
4. Brown, loc cit.
5. National Association of Home Builders website. (1996). (http//:www.nahb.com).
6. Ince and McKeever. *(1995). The Role of Markets and Technology in Conservation of Timber Resources.* Forest Products Lab.
7. World Resources Institute. (1993). Environmental Almanac.
8. Robertson, Lance. (1997). Sustainable products catching on. The Register Guard, Eugene, Oregon. Dec 8.
9. Friedman, A., and V. Cammalleri. (1994). Reducing Energy, Resources and Construction Waste Through Effective Residential Unit Design. *Building Research and Information, 22:2.* 107.
10. Wilson, Alex. Cement and Concrete: Environmental Considerations. *Environmental Building News, 2:2.*
11. Lyle, John Tillman. (1994). *Regenerative Design for Sustainable Development. New* York: John Wiley and Sons. 119.
12. Friedman, Avi, and Vince Cammalleri. (1995). The Environmental Impact of Building Materials in the North American Building Industry. *Building Research and Information, 23:3.* 165.
13. Trus Joist MacMillan. (1996). Product literature. Boise, Idaho.
14. Friedman and Cammalleri, loc cit.
15. Construction Waste Management: New Industry Challenge. (1996, *Nov 18). Nation's Building* News. National Association of Home Builders. 1.
16. Malin, Nadav. (1996, September/October). On Using Local Materials. *Environmental Building News, 5:5.*
17. Fossdal, Sverre, and Knut Ivar Edvardsen. (1995). Energy Consumption and Environmental Impact of Building. *Building Research and Information, 23:4. 224.*
18. U.S. Department of Energy. (1995, October). OBT Buildings Data Summary Sheets. *Office of Building Technologies Core Databook on Industrialized Housing.*
19. U.S. Congress, Office of Technology Assessment. (1991). *Changing by Degrees: Steps to Reduce Greenhouse Gases,* OTA-O-482. Washington DC, U.S. Government Printing Office.
20. Brown, G. Z., P. Kumar, P. Larocque, and Z. Wang. (1995). *Stressed Skin Insulating Core Panel Demonstration House Thermal Testing Report* 9 159/R95-2:tb. Center for Housing Innovation, University of Oregon.
21. Wood Truss Council of America. (1996). Framing the American Dream [brochure].
22. Engineered Wood Association. (1995). Essential Ecology. from CRBT web site: [http://www.montana.com/crbt/].
23. Ince and McKeever, loc cit.
24. Friedman and Cammalleri, loc cit.
25. Wood Truss Council, loc cit.
26. Anderson, Stanford. (1995, November). The Acorn House: Lessons from the 'Complete Dwelling.' *Architectural Review, 68.*
27. Brown, G.Z., P. Kumar, and P. Larocque. (1995). *University Housing Thermal Testing Report* 8326/R95-2:TB. Center for Housing Innovation, University of Oregon.
28. Brown, Kumar, Larocque, and Wang, loc cit.
29. Brown, Kumar, and Larocque, loc cit.
30. Rudd, Armin and Subrato Chandra. *(1994). Side-by-Side Evaluation of a Stressed-Skin Insulated Core Panel House and a Conventional Stud-Frame House.* Florida Solar Energy Center.
31. Brown, *G.Z.* et al. (1997). *On-Grade Panel Floor System,* Center for Housing Innovation, University of Oregon.
32. National Association of Home Builders website. (1997). (http//:www.nahb.com).

Service Life Planning in Building Design

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Abstract
Service Life Planning can be used in all phases of the design of a building. It can be used to set a time scale into the design as well as to consider the environmental aspects of the choice of materials and it can also give information to the consumer about the product he is going to buy and his investments performance over time.

In a research and development project carried out at the Royal Institute of Technology, Centre for Built Environment Materials Division, in Gävle the Service Life Planning is integrated in the design of a building. It is carried out according to the draft ISO-standard IS0 TC59/SC14 Design Life of Building, Part 1 [1]. It is an experiment to test and evaluate the standard. Also guidelines and requirements for further development and research are established.

Keywords: Service Life Planning, building design,

1 Introduction

Service Life Planning is to make plans for the intended use and performance of a building over its whole lifetime. It is a way for the actors in the building industry to reduce lifetime costs and meet environmental requirements.

The research in this area is intended to give a safer and more reliable prediction on how, when and under what conditions a building material or component will deteriorate, thus give a more reliable input for the Service Life Planning. With the knowledge available today in research institutions, universities and building material industry it is possible to make predictions on the behaviour of a number of building materials. An important issue therefore is to transfer this knowledge to the actors of the building market: clients, consultants, architects and contractors etc.

The standard IS0 TC59/SC14, Building Service Life Planning gives a generic description of how to plan for the service life of buildings and its components. Part one [1] deals with specific buildings and part two [2] with test of components in specific environments.

The following definitions are given in the standard:

Service Life	Period after installation during which all essential properties of a material or product meet or exceed minimum acceptable values.
Design Life	Period after installation during which all essential properties of a material or product are **intended** to meet or exceed minimum acceptable values.
Degradation Agent	Whatever acts on a component to reduce its performance

2 Service Life Planning

For a building component the requirements of properties, inherent properties and the degradation environment form the base for the Service Life Planning , se figure 1.

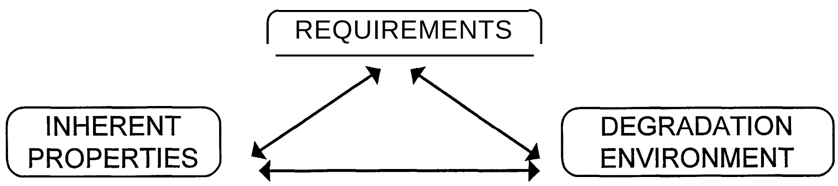

Figure 1. Basis for the Service Life Planning.

The requirements of a building component can be set up by national building codes and/or demands from the customer. Typically demands in a building code are issues dealing with personal safety like load bearing capacity, safety of fire etc. Customers demands could be economic and aesthetic. Demands of environmental safety are of increasing importance.

The requirements of properties are closely linked to the inherent properties of a component e.g. heat insulation, paint, load bearing member etc. But to estimate the behaviour over time one also have to consider the degradation environment i.e. all factors that will have an influence on the functionality of the building component as: wear and tear, mechanical impact, wind, rain, temperature, and air pollution.

The degradation environment can be described in four levels: **macro-region** country, **meso-**urban area, local-road/building and **micro-building** component [4], [5].

2.1 Scope, Method and Result

In a project where a modular building system in high performance concrete is developed the scope is to, in accordance to the draft standard IS0 TC59/SC14, Building Service Life Planning, part 1:

- Integrate Service Life Planning in the design of a building.
- Establish Design Life of Components, DLC.
- Make estimations of the Service Life of Components, ESLC.
- Evaluate the result

The Service Life Planning for each phase in the design is carried out in three phases in an iterative process: **planning** where requirements are set, **estimation** where the performance is checked whether it meets the requirements or not and **evaluation, see** figure 2.

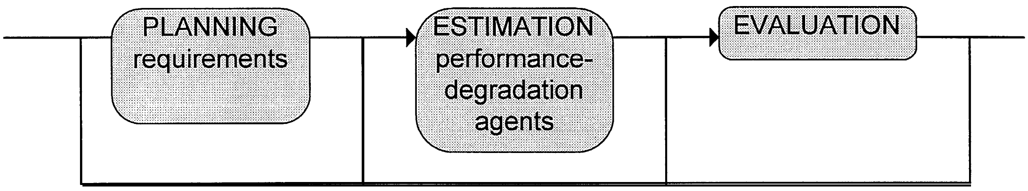

Figure 2. Service Life Planning in an iterative process in all phases of design, initiation, briefing, conceptual and detailing.

The results of the Service Life Planning are meant to be used primary to improve the design process and the design in:

- choice of components and materials
- exterior and interior detailing
- detailing of services

and in addition for:

- maintenance plans
- Life Cycle Assessments, LCA
- Life Cycle Cost, LCC calculations

2.2 Service Life Planning in Design

In the design of a building the documents, written and drawings, will turn to a higher grade of detailing as the process goes on. An assumption is therefore made that the Service Life Planning also has to be performed in that order. Table 1 gives an example on how Service Life Planning will fit into the design of a building. The design process is described in four phases: initial, briefing, conceptual and detailing.

	DESIGN		SERVICE LIFE PLANNING	
Phase in design process	*Drawings*	*Written documents*	*Service Life Planning*	*Degradation environment*
Initiation of a building project.		Short description of the project	Intended use of building	Macro- northern Europe Sweden
Design brief	Briefing sketch	Design brief	Set Design Life of Building, DLB.	Meso- urban area
Conceptual design	Drawings scale 1:200 plans and sections.	Function description Performance requirements	Set Design Life of major Components, DLC.	Local- location in city, wind, driving rain
Detailed design	Plans 1:100, 1:50 Facades Sections 1:50 Details	Building description Specifications of materials	Calculate the Estimated Service Life of the Components, ESLC.	Micro- degradation agents affecting a component

Table 1. Links between the Design and the Service Life Planning.

2.3 Initiation - Design brief

The thoughts of which service life a building have, has to be dealt with in the initial stages of a building project. The actual use of the building if it is a museum, small industrial building, temporary shelter, dwelling the planning of its lifetime use is an essential part of, or should at last be, of the initial process.

In the design brief for a new building generally no decisions on the layout and material choice are taken. The location, the intended use and the expected or desired lifetime of the building have to be formulated. This will give an input for the further going process of the design.

Use of building	Dwelling
Design Life of Building, DLB	The intended time for using this building is 60 years.
Criteria for reach of Service Life	Major refurbishment of the building.

Table 2. Result of Service Life Planning in briefing.

What is then the service life of a building? It could be this that several major changes of systems like service, roofing, facade etc. will take place at this time. All systems will during the lifetime be maintained, but on a certain stage the maintenance cost will be to high compared to the value of the building. It could also be that the function of the building is obsolete i.e. the building does not meet the demands of its time. See also figure 3.

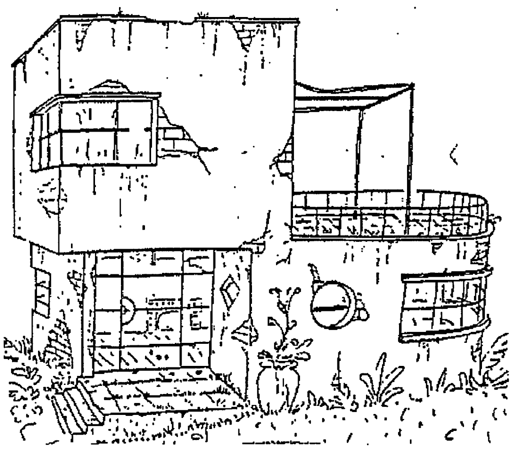

Figure 3. When has a building reached its Service Life.

2.4 Conceptual Design

2.4.1 Planning

Requirements for main assemblies: structure, inside and outside envelope and service systems are set up and evaluated at this stage in the design process.

One of the requirements is the Design Life of the Components, DLC. These are at this stage assumptions based on order of appearance in the building and previous knowledge and experience. Different components that meet the requirements will have different DLC. Example roof: felt, concrete tiles and zinc plates meet the requirements but will have different DLC.

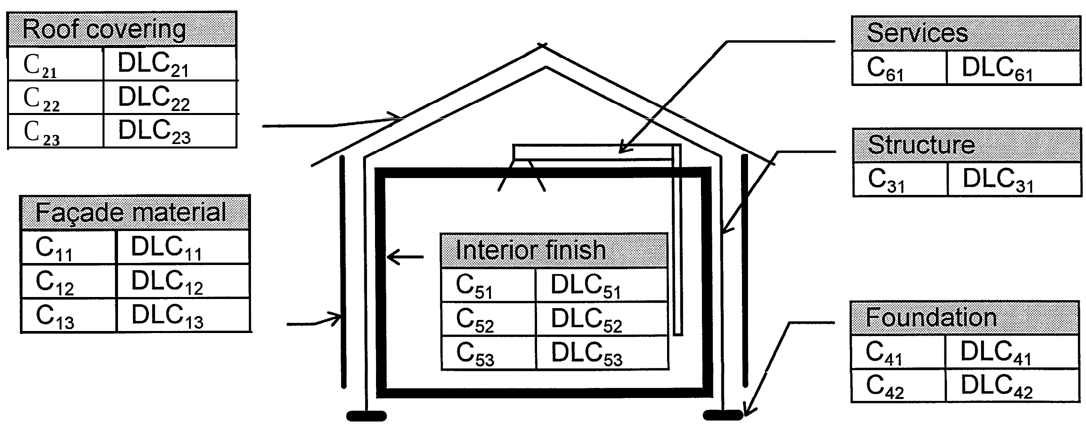

Figure 4. For different assemblies that meet the requirements, appropriate DLC´s are assumed. Examples, where C_{IJ} is a component and DLC_{IJ} its Design Life.

DLC's have also to be set according to the expected lifetime of the function of the component and possibilities to change systems in the future maintenance. It means that DLC is lowest for the interior finish and highest for the structure.

A quality approach to the Service Life Planning is to set the demands to the right service life, i.e. the service life which will give the best value for its purpose. A too long or too short service life will likely add extra cost. The long, in too high investment cost and the short in too high maintenance cost. Maybe these costs in a long term will level out.

2.4.2 Estimation - Evaluation

The DLC's are now treated as a requirement among others when different systems are evaluated.

In the actual case the structure is built from three dimensional elements made of high performance concrete. Therefore detailed estimations on the service life of these parts can bee done already at this stage. The 3-d volumes are also designed to be moveable. This will add the opportunity to reuse the building in an other place as it is likely that the technical service life will exceed the DLB.

In the design of the external wall a there have been discussions on the choice of façade system, or the role of the façade. The following standpoints have been taken into consideration, in addition to the demands of the building code.

- investment cost
- maintenance cost
- architectural expression
- environmental impact
- functionality, flexibility
- service life

From this a matrix discussion is set up on a limited number of solutions. This wav to discuss is set up for a number of main assemblies se figure 4.

External Wall - Façade

Function	Monolithic		
	Stratified		
Production	On site built		
	Factory made		
Material	Plaster	Plaster direct on insulation	
		Plaster on ventilated board	
	Boards	Fibre cement	fit on wood
			fit on metal
		Fibre cement, type Glasal	fit on stainless steel
		Ceramic plates	fit on stainless steel
		Coil coated steel	

Figure 4. Principles for matrix discussion on choice of façade.

The result of the discussion, from a Service Life Planning point of view, is summarised as follows:

- It is easier to describe the degradation environment for a stratified wall i.e. each layer has few functions.
- With factory built materials more reliable predictions of the service life can be made as it is not affected by the weather conditions on site.
- For the production, with moveable units, a reusable factory made plate facade is more suitable.
- A facade with ventilated plaster has a more predictable behaviour than a non ventilated.
- A facade with plates fit on metal bars will have a longer service life then plates fit on wood.
- Ceramic plates fit on stainless steel will have the longest service life, but does it have the right?
- Plates will be easier to maintain if single plates are fit to be able to change.
- A metal facade is recyclable.

The statements above are not objective truths based on scientific evidence but are evaluations based on experience. They can also be seen as guidelines for future research in the fields of durability and service life. E.g. ageing or long term tests on assemblies of components.

Anyway these discussions will end up in a table of DLC´s, table 3.

Building assemblies		***DLC Minimum***		
		alt 1	alt 2	alt 3
Load bearing members	foundation	DLB		
	vertical structure	DLB		
	horizontal main structure	DLB		
	stabilising members	DLB		
Non load bearing partition wall		25		
Roof	covering	15	25	40
	structure	DLB		
External finishing	facade material	25	40	DLB
	heat insulation	25	40	DLB
Fixings	external	40		
Services	ventilation	40		
	water	40		
	sewer	40		
Drainage	below ground	25		
External works		25		

Table 3. Design Life for major Components.

The values in the DLC table will in the next phase of design be compared to more detailed estimations on the service life of components.

3 Detailed Design

Here is given a brief description of the detailed design A separate report will later be prepared to present the detailed Service Life Planning.

In the detailing phase of the service life planning, estimations of the service life of the components are made. The estimations are based on the requirements, the inherent properties and the degradation environment and will be carried out with the factorial coefficient method proposed in IS0 TC59/SC14, Building Service Life Planning, Part 1, [1].

The equation for calculating the estimated service life of a component is given below:

$$ESLC=RSLC*A_1*A_2*B*C*D_1*D_2*E*F$$

Where

ESLC = Estimated Service life of a Component

RSCL = Reference Service life of a Component, which is a result of a test in a specific condition. The ideal is that these test are carried out according to IS0 TC59/SC14, Building Service Life Planning, part 2.

Factors A to F are described below:

F-actors related to nherent quality characteristics	4_1	Performance of Materials	Material type or grade. Manufacture, storage, transport.
	A_2		Durability features: Protection system.
	B	Design level	Details of construction: Joints fixing, incorporation, sheltering by rest of structure.
	C	Work execution level	Site work: Quality to standard or manufacturers specifications. Level of workmanship, climatic conditions during execution work.
Environment	D_1	Indoor environment conditions	Condensation, aggressiveness of environment, ventilation.
	D_2	Outdoor environment conditions	Elevation of the building, micro environment conditions, traffic emissions, weathering factors. Marine or polluted.
Operation conditions	E	In use conditions	Mechanical impact, category of users, wear and tear, vandalism.
	F	Maintenance	Quality and frequency of maintenance, accessibility for maintenance.

The ESLC´s will thereafter be compared with the DLC´s of table 3 and different actions will then be taken if ESLC differs from DLC. These actions could then be anything from just accept the difference to make a complete re design. It all depends on the cause and the consequence of the difference.

The quality of the estimation will be totally dependent on the input. Sources for input will be

- planning material manufacturers
- estimation reports from research
- experience from practice

4 Conclusions

The Service Life Planning can not be separated from the design of a building. This paper will show how this concept can fit in to the design process of buildings and how it can be used to improve the design.

The paper will also show that there is not only need for service life data of materials. It is also necessary to discuss general principles like

- factory built material - in situ built material
- stratified assemblies - monolithic structures

how they behave in the long term and how they affect the ability to predict service life.

5 Acknowledgements

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6 References

1. *Buildings - Service Life Planning, part 1, General Principles*, IS0 TC59/SC14 DRAFT 3: October 1996.
2. *Buildings - Service Life Planning, part 2 Service Life Prediction Methods*, ISO TC59/SC3/W59 DRAFT 1: March 1997
3. Bourke K. and Dawis H., *Factors affecting service life predictions of buildings: a discussion paper*, BRE, September 1996.
4. EOTA, *Assessment of Working Life of Products*, PT 3 - Durability, Final Draft - October 1996.
5. Haagenruud Svein E., *Environmental Characterisation including Equipment for Monitoring*, CIB W80/RILEM 140-PSL SG2 Report,Kjeller Norway, 1997.

System applied in Poland for assessment of products and technologies for sustainable construction

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Abstract
The paper examines the principles of products and technologies for sustainable construction, applied in Poland. The assessment is carried out for two stages.

The first phase encompasses designing and the stage at which the building is constructed, taking into consideration the consequences of acquiring raw materials and the process for producing the materials and products.

The second phase of the assessment is the assessment of the building during its period of exploitation, which includes the living conditions of people in the building, the impact of the building on the environment and the service life of the elements and the whole building.

The basic elements of assessment and their systematics are given for these two phases.

The paper presents the provisions of the basic Polish building regulations affecting sustainable construction, i.e. the acts on environmental protection, on spatial management and the building law act. The acts are supplemented by executory ordinance issued by the appropriate ministers.

An important role in the system of these regulations is performed by the regulations determining the principles for assessing the innovative and non-standardised building products.

The paper informs about scientific research connected with sustainable construction, conducted in the Building Research Institute. The systematics of this work is to a large extent based on the set-up of basic requirements according to Directive 89/106/EEC.

Key words: assessment, buildings, products, sustainable construction

1 Introduction

If we agree with Bruntland's definition of sustainable development as ,,Development that meets the needs of the present without compromising the ability of future generations to meet their own needs", then one of the basic elements of such development is sustainable construction.

The Polish act on environmental protection states that sustainable development means such socio-economic development, in which in order to balance out access to the environment of various societies or their citizens - both present, as well as future generations - there occurs a process of integrating political, economic and social activity, maintaining an equilibrium in nature and the durability of the basic natural processes.

The building industry, in all of its phases of construction and exploitation of the building, is one of the basic factors affecting sustainable development.

Assessing building activity from the point of view of sustainable development we stress two aspects of this problem:

- the necessity of satisfying the needs of the present generation, requiring making short-term decisions i.e. for the contemporary users of the building and
- the requirement to act in such a way, so that today's activity does not prevent the fulfilment of the needs of future generations, and this means an assessment of the long-term effects of the investment decisions made today.

Construction which is conducted in accordance with the principles of sustainable development may be defined as sustainable construction.

The system of assessing construction products and technologies and buildings which considers the principle of sustainable construction includes its three phases:

- programming and designing,
- realisation,
- exploitation.

It is the task of the state authorities to create such a system of regulations, which would place the duty on all of the participants of the investment process to follow the principles of sustainable development and provide the basis for carrying out objective assessments by independent organisms.

Programs for educating building specialists should include knowledge enabling assessment of the designed and applied functional and technical solutions for sustainable construction.

The Building Research Institute - ITB conducts scientific research aimed at formulating the technical-service requirements for building products and buildings, as well as the criteria for fulfilling these requirements. This work takes into consideration the principle of sustainable construction.

2 Elements of assessing materials and technologies for sustainable construction

2.1 The investment process

In designing the first element of assessment is the building's location in the area, taking into consideration first of all assuring harmony with the environment. We consider rational use of land, including investing in areas with the lowest land class and ensuring the lowest degree of devastation of the natural environment, including water and air protection, taking into account the local climatic and geopatic conditions

The adopted set-up of building complexes, the accompanying municipal and internal transport systems, the municipal infrastructure and the correct insolation, ventilation and protection from noise conditions all take part in creating sustainable construction.

Adopting technical-service requirements in the design set for buildings, given in the national regulations in force, should not solely have a formal character, as the regulations set the requirements at a minimal level. They should only be a reference point for the solutions adopted in the design. Building designing cannot omit planning the service life of elements and entire buildings as the period of service usefulness of various elements and the entire building is not the same, and the end of service usefulness of the various elements does not signify the physical destruction of the building.

The production of building products significantly affects sustainable construction. The first element of assessment involves the way in which the raw materials, to a significant extent of natural origin, are acquired. This is connected with the need to conserve natural raw materials, utilising unused raw materials and recultivating post-mining areas.

Assessment of industrial production of building materials considers the physical and chemical factors connected with the technological process, such as air pollution, noise emissions, building industrial waste landfills. The following elements should also be considered: decreasing the energy consumption of production processes, decreasing the amount of technological wastes produced, and the possibility for recycling them, or utilisation for producing other materials.

When assessing the process of constructing a building we consider the temporary impact of a similar type as in the case of industrial production, e.g. energy consumption or noise emissions, and permanent consequences causing the degradation of land, such as a change of water conditions and destruction of trees.

2.2 The building during exploitation

The basis for creating sustainable construction is the correct formation of mans environment in the building. Analysing the biophysical reactions of the human organism, factors which decide on man's environment in the building include:

- temperature of the surroundings
- air humidity
- air circulation in rooms
- chemical and dust air pollution
- noise in the audible range
- ultrasounds
- vibrations
- effect of the electromagnetic field
- ionising radiation
- effect of micro-organisms

The selection of appropriate technical solutions for entire buildings, their elements and the used materials prevent the negative consequences of the factors mentioned above. A fragmentary approach to these issues, by specialists from different areas, is insufficient, as creating a building which would be „friendly" for humans requires all of these factors to be taken into account.

Elements which assess the service values of buildings also include safety and convenience of use (according to Directive 89/106/EEC) and the possibility of functional transformations of the building in the future.

When assessing the building during exploitation, its impact on the environment should also be considered, and in particular:

- emission of gasses
- emission of noise and vibrations
- method of disposal and treatment of sewage
- method of storing and utilising municipal wastes.

The service life of the building is not only an economic factor, but it has significant influence on creating a sustainable construction, as assuring the necessary service life of the building, materials and products decreases the amount of waste which may cause environmental pollution. The building's durability well serves, among others, the ease with which the good technical state may be maintained and the reliability of protective insulation. The service life is also connected with the results of renovations, modernisation and demolition of buildings and the possibility of recycling in-built materials.

The main elements of assessing materials and technologies are presented in Table 1.

Table 1 Elements of assessment of materials and technologies for sustainable construction

Assessed period	Problems	Elements of assessment
Investment process	Designing the building	• location of the building - harmony with the environment • rational land use • protection of water and air • technical-service requirements for the building • planned service life of elements and buildings
	Production of materials	• acquiring raw materials • environmentally-friendly industrial process
	Building process	• temporary impact during building • permanent effects on the environment
Building during exploitation	Man's living conditions in the building	• physical factors • chemical factors • biological factors • safety and convenience of use • ease of functional transformation
	Building's impact on the environment	• emission of gasses • emission of noise and vibrations • disposal and treatment of sewage • storing and utilisation of municipal waste
	Building's service life	• ease of maintaining good technical state • reliability of protective insulation • results of renovations, modernisation and demolition of buildings • possibility of recycling in-built materials

3 Polish regulations regarding sustainable construction

The act on protecting and forming the environment (amended in August 1997) introduces the principle of sustainable development, defining its aims. The act gives a series of requirements connected with environmental protection, which greatly influence the creation of sustainable construction. These requirements refer to:

- protecting the surface of land and minerals
- air protection
- protection from noise and vibrations
- protection from radiation

- impact assessments of investments or buildings on the environment.

In the act on spatial management amended in September 1997 the principle of sustainable development is adopted as the basis for activity connected with spatial management. This has direct effect on determining the conditions for land development and for locating areas for acquiring mineral building raw materials.

The act on the building law (amended in September 1997) creates a good basis for assessing materials and technologies for sustainable construction. The act states that a building should be designed, built, exploited and maintained in accordance with the regulations, in a way conforming with, among others, the basic requirements (according to Directives 89/106/EEC), the service conditions and protection of the justified interests of third parties. The building law requires that when carrying out construction works building materials should be used which would enable correctly designed and built buildings to conform with the basic requirements - formally permitted for turnover and use in the building industry. The procedure for allowing building materials in turnover and use lies in confirming the confirmity of the properties of the materials with properties given in the Polish Standard or technical approval provided for innovative or non-standardised materials. The technical approval according to Polish regulations gives the service properties and technical properties of the material and is a positive technical assessment stating the material’s usefulness in the building industry.

For most building materials the technical approval is issued by the Building Research Institute, which is a member of UEAtc.

The certificate issued by the unit authorised by the Polish Centre of Research and Certification or a declaration of confirmity issued by the producer confirms confirmity with the Polish Standard or the technical approval.

The following elements are determined on the essential of the building act by instructions of the respective ministers:

- technical conditions, with which buildings should comply and their location
- technical conditions for exploiting buildings
- acceptable concentrations and intensity of factors harmful to health emitted by building materials.

On the basis of the act on standardisation the minister responsible for the building industry prepares a list of Polish Standards which must be adhered to.

The presented system of the regulations in force in Poland forms a broad legal basis for:

- formulating requirements for building materials and technologies for sustainable construction,
- assessing whether these requirements are fulfilled.

4 Research conducted in the Building Research Institute - ITB

In the framework of statutory activity of ITB financed by the state budget work is currently being carried out on researching the problem of sustainable construction. This work is encompassed in problem groups. Six problem groups, partially referring to sustainable construction, encompass issues resulting from basic requirements given in Directive 89/106/EEC, for buildings, i.e.:

- mechanical resistance and stability
- safety in case of fire
- hygiene, health and the environment
- safety in use
- protection against noise
- energy economy and heat retention.

A very important requirement taken into consideration when assessing building materials and entire buildings, connected with sustainable construction, is the service life. This is why one of the problem groups is devoted to service life (including corrosion, chemical and biological protection, protection from humidity).
Two problem groups are connected with the specific character of exploited buildings and refer to:

- diagnosing the technical state of the building
- the technical aspects of maintaining and modernising the existing building resources.

The problem group called „ecology of the building industry" is directly associated with sustainable construction. This group includes mainly research topics regarding the surroundings of buildings, such as:

- soil and water protection when building municipal waste landfills
- building industrial ash disposal sites
- derelict land management
- the consequences of the vicinity of facilities generating vibrations
- methods for rationalising and utilising energy in buildings due to dust and gas contamination in the environment.

References

1. Wierzbicki, S.M. (1996) Building Industry and Environment, *Proceedings of CIB TG-8 International Research Workshop - Building and Environment in Central and Eastern Europe,* Warsaw, Poland.
2. Construction and Environment *(1994) Proceedings from the 40th Conference on Research problems in construction,* Krynica, Poland.
3. Wierzbicki, S.M. (1995)Construction and suistainable development at human environment. *Proceedings from the 7th Conference on Ecology and construction,* Bielsko-Biała, Poland.

Ecological, Low Energy and Low Cost Housing Possibilities for Latvia

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Abstract
The goal of this work is the minimization the housebuilding and maintenance costs and to create a possibility to obtain the dwelling for the families with a middle and low income. The main reserves for this goal are as follows:
- The optimization of the geometry for the load bearing external structures and their materials properties for reduce their size and the prime cost of the construction.
- Essential improvement the heat insulating properties of the windows, external walls and roofs by use cheap an efficient insulating materials.
- Utilization the mass industrial pollutants, coming out from the paper, wood and some other non-toxic chemical industries for production the cheap and high-effitive building materials and elements.
- The harmonization the housing architecture with the economy of the construction and with the non-expensive long-time maintenance.
Keywords: Ecology, external walls and roofs, heat losses, industrial pollutants, load-bearing capacity, thermal resistence, low-cost housebuilding, middle class, structural optimization.

1. The Problem

The dwelling-house building in Latvia during the past 5 years is almost stopped because the Government has no finances for this purpose, but the housing indigence for the people is still remained. Our new peasants often must start their life in an unhabitated field because during the Soviet occupation time the individual farms are destroyed or collapsed.

Only some new private companies have **built** new dwelling-houses and here two directions are obvious:

- The building company have bought from the municipality an unfinished government multistory dwelling house or only the foundation. The layout than is quite transformed - the number of the flats is reduced and their dwelling space is essentially increased (5...7 rooms and more). The comfort level is enlarged - the fireplaces, saunas, swimming baths, interior gardens and studios are built. The dwelling price in such houses is very high, it is about 250-350 Ls per.sq.m (430-600 USD per sq.m).

- The building the one-family houses according to the individual design. They are built very large (2-3 storey and more) with two and more car-ports, saunas,closed or open-air swimming pools, gymnasiums, sporting grounds, high reinforced concrete fences, and different safe-quard systems. The comfort level than is much higher like in our average dwellings, and the building price is about 400-500 Ls per sq.m (690-860 USD per sq.).

These **said** two versions, and the second especially, are available for the small quantity of our new riches only. So the requirements of the big amount of the majority population families with middle and low income are quite ignored. The approximate distribution of the potential and non-potential dwelling buyers is showed on the enclosed diagram (see fig. 1) in dependence of the 1 sq.m.price in USD. It is obviously how with the lowering the price the total amount of potential buyers could grow essentially. The white area here is the potential buyers of the middle class not yet very developed in the post-Soviet liberated states. Also it is obviously the greatest part of the people could not buy a dwelling, because the lowering the price less than 100-150 Ls per sq. (170-260 USD per sq.m) is very problematic for the construction. Exactly this diapason is the research field for our Center.

2. The Reserves

What is the real possibilities for building new type affordable dwelling-houses **with** normal comfort level **but** cheap in **the** construction and **in the** maintenance also?

The investigations done in **the** Riga Technical University show **us** four reserves:

1. We have stated the fact in the real house structures the strength of the materials is not completely utilized and the hidden reserves of their load bearing capacity are very large. For the mainly amount of the dwelling houses the ceiling and roof reinforced concrete slabs **about** 50% **of** the concrete volume is placed in the tensile zone and here the concrete does not work, here is working only the reinforcement only. The compression stress in the brick masonry or in different block walls for five storey houses is less than **40% of** their compression strength, but in 1-2

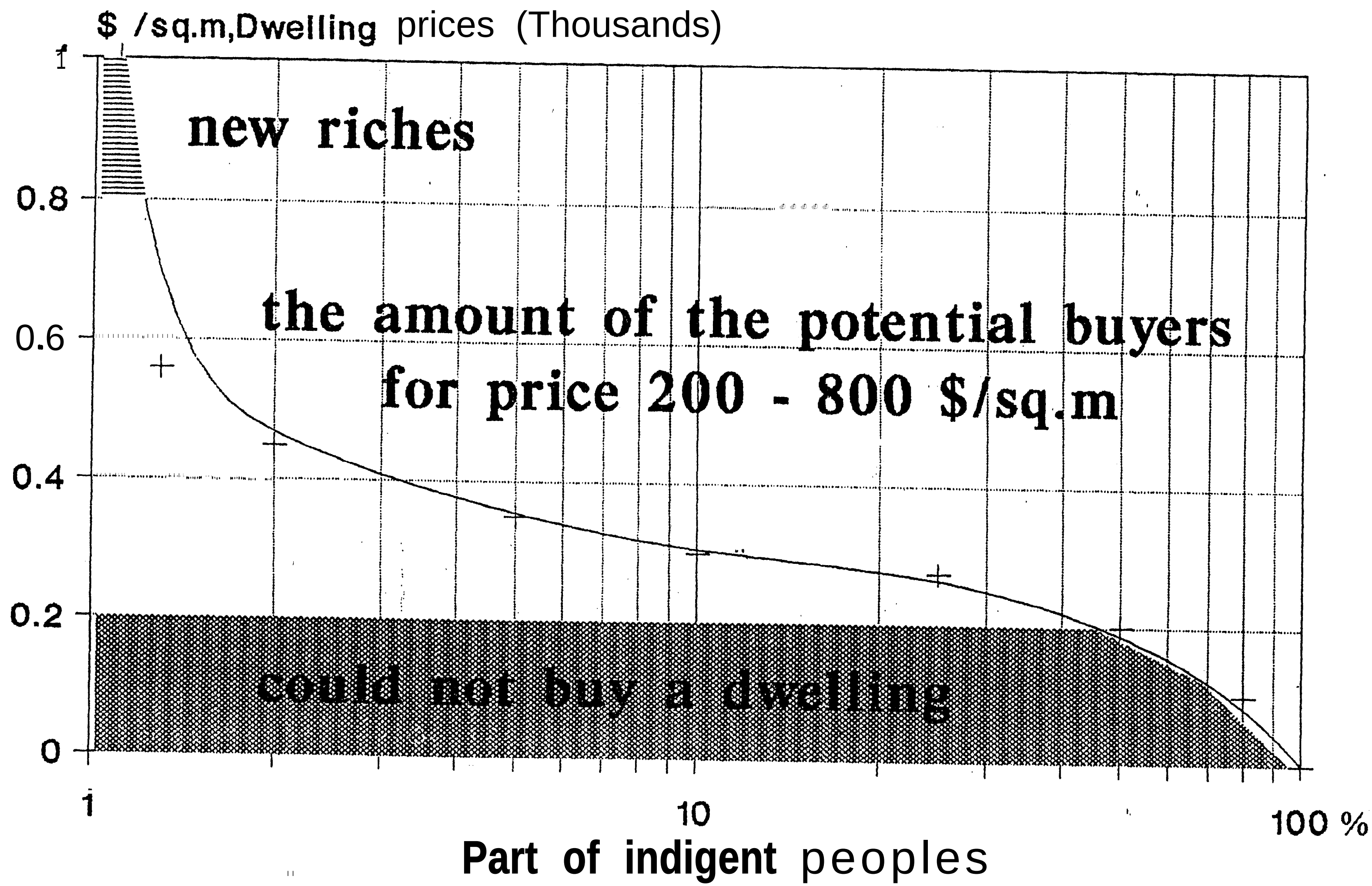

Fig. 1. The result of a social questioning about the distribution the potential house–byers and dwelling–byers depending of the one sq.m. dwelling price.

floor house it is about 6-10 % only. It is due the contradiction between the external wall big thickness necessary for the heat resistance and very small thickness which is necessary for the load-bearing function. In the foundation structures the situation is very worse - the stress is only 4-8 % of the concrete compression strength and is closely at the stress in the soil.

All other amount of the load bearing material is an expensive worthless stuff, but in the case of external walls and other outside structures, it is a very harmful ballast of the masonry or the concrete which is conducting the heat out from the house interior.

As it is indicated, these reserves could be converted into a very great economy if use new types of rational designed load bearing structures with the optimized sections and homogenized compression stress distribution.

2. Our new buildings, and these ones builded in the Soviet time especially, are not economical not only for the construction but for the maintenance also. Their heat losses (the u-value) through the walls, roofs and windows are 2,7-3,1 times more than the recent Building Codes of the North European States (Finland 1985, Denmark 1995) have permitted. For the existing external walls the real heat losses are 1,0-1,2 W/K.sq.m. But during the last 3 years the fuel prices in Latvia are raised catastrophically - for the earth gas the price have raised more than 600 times.

For the new building these reserve could be turned in an economy when in the rationally designed outside structures for walls and roofs the most part of their volumes will be replaced with high effective heat insulating materials.

For the existing buildings an effective additional heat insulation for the external constructions and triple-glass windows must be applicated. Always must be accounted fact that during the long life of the house the prices for the heat will grow up more and more, and the Building Code requirements will become stronger like nowadays.

These arrangements will give not only the economical, but an ecological benefit also, because the air pollution with the combustion products - the oxides of the sulphur, carbon and the azote, will be minimized.

3. It is a very big amount of different industrial wastes and pollutants coming out from the Latvia industry. In our investigations it is created simple technological processes for produce cheap heat and sound insulating building materials, the lignocomposites included, on the basis of the full utilization the wastes of the cellulose, paper, woodworking, forestry and timber industries. No one other branch of the industry can "swallow" so large amounts of the mass industrial pollutants like the building materials industry. So the ecological benefit here is the prevention the pollution of the rivers, forest and soil. For making cheap heat insulating composite materials in the technology could be utilized also some by-products and cheap local raw materials like the straw, boon, waste-paper, peat and low grade clay. The amount of these raw stuff in Latvia is more than sufficient. Wery actual for Latvia could be the production and use also the Eco-Fiber insulation made by utilizing the recycled waste paper.

Also special heat insulating materials, like plastic foams, rockwool, glaswool, aerated gypsum and others could be here used, but the practical utilization of the said ecological reserve could be essential cheaper.

4. The harmonization the housing architecture with the economy of the construction and the 1ong-time maintenance. It means the use the modulus-systems of load bearing structures for reduce the prime-cost of industrial house building. It means also the location the warmer parts of the house - the bath, sauna, stove, fire-place in the middle of the layout. The solar energy and the green-house effect for the external walls and roofs also could be used here as an important additional heat source. For the windows it means the use of the third-pm oriels. The ceiling must be joined together with a good insulated roof. The additional heat insulation for the soil will allow to use shallow and cheap foundations. Often the houses have very broken layout, stepvise vertical sections and unnecessary complicated rofs. So such houses obtain a very big external cooling surface, which must be essentially minimized. For exclusion the wind air infiltration the facade must have a simple and aerodynamic shape.

3. The way out of the situation and proposals

For evolution the scientific basis for the ecological and economical house-building, at the Riga Technical University an Ecological & Low Cost Housing Center in the 1994 was founded. We have elaborated some amount of real technologies and proposals for effective realization the said reserves in the building praxis, and here are 16 Latvian patents.

They are new ecological and cheap heat insulating materials (Ligno-Concretes and others). They are also new external wall structures - the Thermo-Blocks and Thermo-Panels and methods for heat saving in existing precast concrete houses. In each case the prime-cost of the constructional utility function (strength, bearing capacity, thermal resistance) for the new materials and building elements is very cheaper like for the traditional ones.

Thermo-Blocks are a new type external wall elements predestinated for 1-3 storey single-family houses. In contrast to the traditional one-material homogenous blocks made from lightweight aggregate or cellular concrete, wood concrete a.o., the Thermo-Blockes /1/ consist from two components - the load-bearing material part and the heat insulating material part. The load-bearing material - usually the concrete, must have the highest compression strength possible for each real producer, because in this case the cost of the strength will be the lover. The load-bearing material in the volume of the Thermo-Block is located accordingly to the following requirements:

1. The maximal moments of the inertia must be obtained with simultaneus minimization the horizontal load bearing section.

2. A homogenous (rectangle) distribution for tie compression stress in the load bearing horizontal section must be so obtained. Therefore the axis of inertia of the load bearing section are located in the some vertical flat where the resultant loads acts. Only in this case the full utilization of the concrete bearing capacity will be ensured.

3. The horizontal section of the load bearing material, and consequently, the concrete volume and expense are directly so great as it is necessary for the load bearing function in accordance to the Building Regulations, and no more.

4. To ensure the easy, high productive and cheap technology for Thermo-Blocks casting.

Only the respect of the requirements 1, 2 and 3, and when the maximal strength is warranted, give us a possibility to minimize the volume and the cost for the load-bearing material's part. In this case we can include in the other part of the wall volume the maximum amount of the cheaper heat insulating material, which is choosed with the minimal density, i.e. with the minimal thermal conductivity. The heat insulating materials (plastic foam, rock wool, ligno-composite and alike) usually are very cheaper than the high-strength concrete, and in such a way the cost of 1 wall cub.m. could be minimized, but the quality - the thermal resistance, will be increased essentially.

For example, when the wall thickness is 30 cm, the specific heat losses (the u-value) could be easy decreased till 0,25 W/sq.m.K. So effective result could be compared with a cellular concrete block wall with thickness 70-80 cm, or 115 cm thick expanded clay (Leca) blocks masonry,or the clay brick wall with 2,95 cm thickness.

This means the reduction the heat losses for about 4 times, and a similar decrease the cost of the heat resistance, what is the main external wall's function.

In a specific conditions, for example, in country-side, for the heat insulation stuft main components in the Thermo-Blocks could be used some wastes or local raw materials: the conserved and prepared with binder straw, boon, saw dust, bark, waste-paper, pit and alike For this goal also the Ligno-Concrete /2/ is elaborated. It is an ecological building i t -insulating material produced from the mass wastes coming out from the cellulose and paper industry. The density of Ligno-Concrete range from 350 to 850 kg/cub.m, the compression strength is from 1,8 to 3,0 MPa and the heat conductivity range from 0,08 to 0,18 W/m.K. The heavy weight classes of the Ligno-Concretes could be used for usual wall block casting, but the light weigh classes could be very cheap and effective filling for Thermo-Blocks. This also could essentially reduce the prime cost of the external wall construction.

The technology of the Thermo-Blocks is very simple, and the ordinary building material and detail making machines here could be used.

4. Conclusions

The practical results of the investigations could be as follows:

1. Economical - to essential reduce the house building expenses and to save the heating costs.

2. Social - to solute the cheap shelter problem for the families with low and middle. income and to raise the number of the working places.

3. Ecological - the prevention of the pollution for the environment with industrial wastes and the air with combustion gases CO, CO_2, SO_2, NO_x a.o.

Acknowledgements

These investigation was developed on the basis of the Latvian Government budget grant in the 1993-1997, and now the E & LCH Center of the Riga Technical University is looking for a Government grant in 1998 for the further development and for the realization the practical results of the investigation in the construction.

References

1. Lapsa, V.A., Choochooyev, A.S., Terentyev, A.Y. (1997). The economical problems of the concrete and some technical means to solve it. Proceedings of International Symposium "Prefabrication-Facing the New century", Helsinki, Finland, pp. 46-50.

2. Lapsa, V.A., Betkers, T.E., (1996). Ligno-Composites and their constructional use. Proceedings of the Nordic Concrete Research Meeting. Espoo, Finland, pp. 337-338.

Design guidelines and life-cycle-cost analysis for the use of recycled plastic lumber (RPL) in structures

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Abstract

Significant process improvements have been made in recent years to enhance the quality and consistency of recycled plastic lumber (RPL). Also, standard methods for testing and determining the performance of RPL are being developed by American Society of Testing and Materials (ASTM) Committee D20. The next step involves acceptance of RPL as a structural material in the marketplace. For this to happen, design guidelines must be established to account for the differences in mechanical properties of RPL as compared with wood. This would enable the use of RPL in construction applications where its corrosion and insect resistance, non-polluting properties and low maintenance aspects would make it a useful material. In a pilot project supported by the State of Ohio, Department of Natural Resources and the U.S. Department of Energy the structural aspects and economics of using RPL for shipping pallets were studied. A procedure to integrate field performance with laboratory evaluation was established. Typical properties of RPL were then used to predict the performance of structural components used in construction using advanced numerical techniques. A life-cycle cost analysis (LCCA) procedure developed by the U.S. Department of Energy (DOE) was adopted to investigate the economics of using RPL pallets versus other options at the DOE site. Plans to' expand this pilot project into a multi-client program to develop standards, generalized design guidelines, product specifications and a database of information for RPL in structural use are also discussed.

Key Words: Recycled Plastic Lumber, Life-cycle cost, design guidelines, shipping pallets

1 Introduction and background

Over the last decade recycled plastic lumber (RPL) has been a very key product in converting waste plastics into useful, high-valued, end-products. The manufacturing methods have been shown to be *both technically feasible and economically viable*. RPL can consume large quantities of mixed, waste plastics; is relatively insensitive to manufacturing variables as compared with other processes used to make plastic products; can tolerate high degrees of impurities and contaminants; can be reinforced with other recyclable wastes such as fiberglass or wood flour; and, requires low capital investment in equipment. RPL, which is currently used primarily in non-load-bearing-applications has not fully realized its potential as a structural material.

Even with limited applications, RPL production stands at about 16 million board-feet (5 million board-meters), or 20,000 tons of waste plastics, per year. More importantly, the growth rate of this industry in the US has been about 40 percent per year in the last few years and there are now over 25 manufacturers. The manufacturing processes and types of RPL have been discussed in detail by Krishnaswamy et al [1] and for brevity will not be included here.

2 Objectives

The objectives of this project were to: (1) determine the technology needs for using RPL in structural applications, (2) define a methodology to establish performance based standards for RPL, (3) validate the methodology through experiments, analysis, and field evaluation, and (4) conduct a life-cycle-cost analysis (LCCA) for assessing the economics of use of RPL in structures. The pilot project used shipping pallets manufactured using extruded RPL in a case study. This paper highlights some of the key findings from this project.

3 Technology Needs for Structural Uses of RPL

There are four major obstacles to be overcome for RPL to be accepted in load bearing applications. The first involves development of standards to test, evaluate and specify the various types of RPL based on its' performance. The second major obstacle is the need for design guidelines that will aid structural engineers to use these standardized properties to compute the stiffness, maximum load carrying capacity, and long term performance of structures. The third barrier is the lack of a database or handbook of mechanical properties and durability data for the various types of RPL. The fourth and final barrier is an accepted LCCA methodology for economic justification for the structural use of RPL.

The Plastic Lumber Trade Association (PLTA) consisting of the manufacturers of RPL together with the American Society of Testing and Materials (ASTM) has formed ASTM Committee D20.20.01 to address the first barrier. This group is charged with developing standard test methods as well as performance based specifications for RPL. Five standards [2-6] been -approved by ASTM and several more have been drafted and are under review.

Outside of this project, however, there has not been a concerted effort to overcome the remaining three barriers. Recently, McLaren [7] has discussed the need for a design methodology and proposed a procedure to develop load-duration-factors for designing with RPL similar to those that exist for traditional materials such as wood or steel.

4 Case study - RPL pallet evaluation

4.1 Laboratory experiments and analysis

In this pilot project for developing a design guideline and establishing a methodology for performance based specification, we chose shipping pallets fabricated from RPL as a candidate product. Since shipping pallets are used extensively by industry and government agencies, developing a performance based specification would be the first step in the creation of a procurement guideline. Such a guideline would significantly expand the available markets for RPL. The U.S. Department of Energy (DOE) needed to investigate the use of RPL pallets at some of their low-level radiation sites and determine whether these were acceptable alternatives to conventional wood and steel pallets. The pallets were essentially used to store and transport 55-gallon drums containing low-level radioactive waste.

The structural requirements of the RPL pallets by DOE at their site in Fernald, Ohio were quite severe. The technical report on this project [8] provides details of these specifications. Several modifications to an existing pallet design were made by Battelle and The Plastic Lumber Company based on past experience with heavy-duty pallets. The engineering drawing for the final design of the RPL pallet used in the field evaluation is shown in Figure 1. Based on past experience, this design was considered to be robust enough for the site requirements.

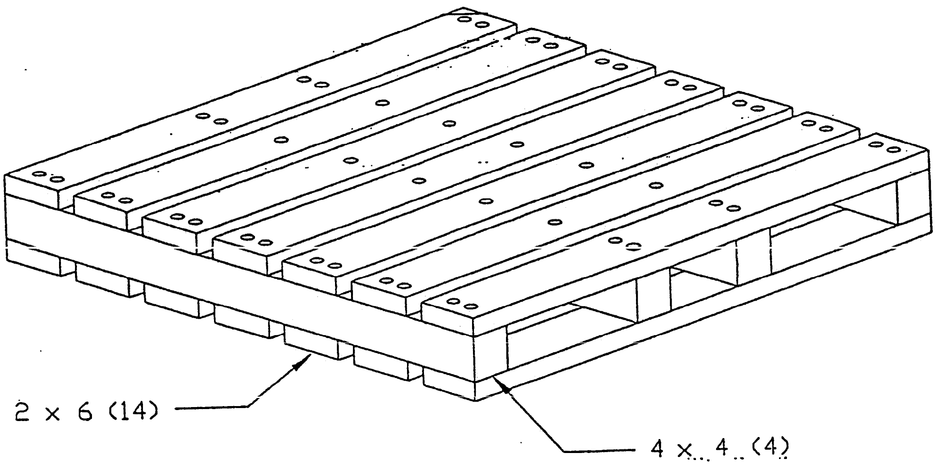

Figure 1. Schematic of the heavy-duty RPL pallet design

However, further full-scale testing of the pallet was conducted to ensure that the load carrying requirements were met. These results are discussed next.

Four RPL pallets were fabricated by PLC as per the above design and the following full-scale tests conducted according to ASTM standards: (1) Stiffness and Flexural Strength tests, (2) Vibration Testing of Pallet Loads, (3) Lateral Stability and Diagonal Rigidity tests due to drops, (4) Impact Test of Leading Edge, Blocks and Posts, and 5) Compression Test of Pallet with a simulated four, 55-gallon drum loading configuration. Details of these test procedures and results are provided [8]. Figure 2 shows the load-deflection curve for the pallet under compression load configuration using four 55-gallon drums. As seen, the maximum load carrying capacity in this test configuration is 20,355 pounds, which exceeded the requirement of 19,200 pounds by DOE-Fernald. The pallets also passed the vibration, drop and impact tests.

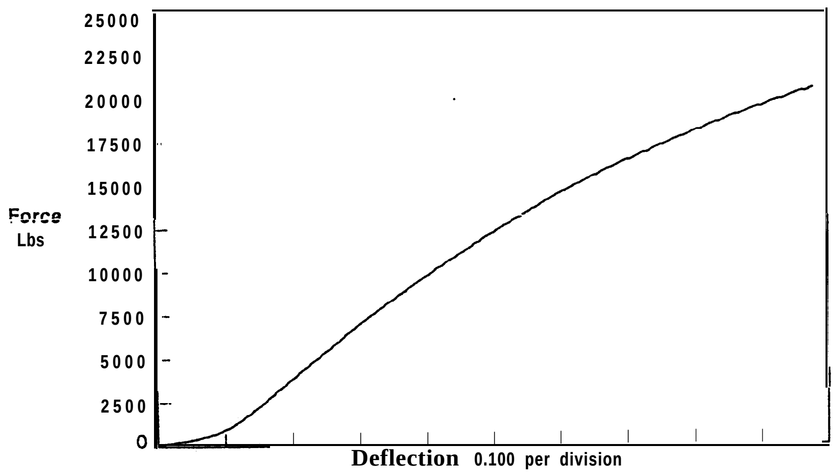

Figure 2. Load-deflection curve from full-scale test on RPL pallet under 4x55-gallon drum

An attempt was made to simulate the full-scale behavior of the pallets using the RPL material properties and Finite Element Analysis (FEA). The mechanical properties required of RPL for the computer simulation included flexural properties for the lumber (2"x6") and the compression properties of the stringers (4"x4"). A typical flexural stress-strain curve conducted using ASTM D 6109 is shown in Figures 3. These data were used in the finite element simulation.

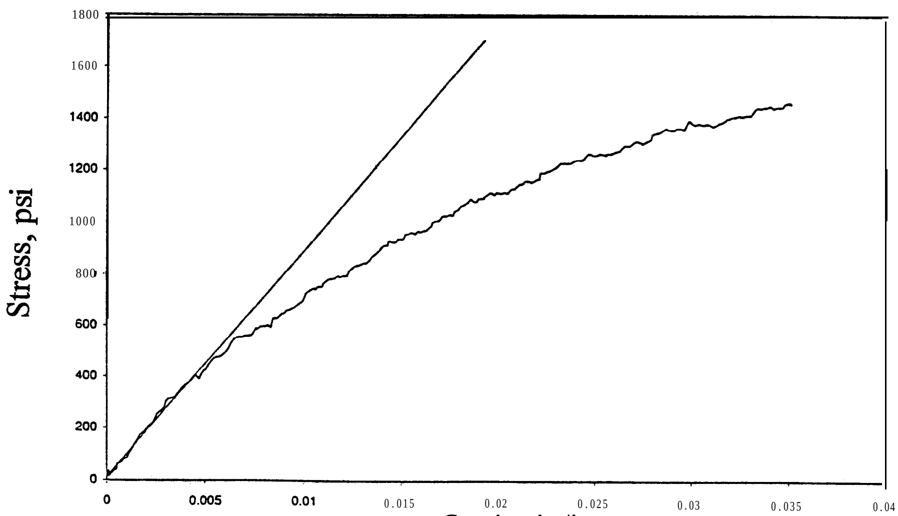

Figure 3. Stress-strain for RPL under flexural loading

A three-dimensional FEA model of one-quarter of the pallet was developed to simulate the full-scale test conducted. The results of the computer simulation indicate that the maximum loads were over-predicted by a significant margin. The level of discrepancy is not unexpected as the RPL is assumed to be homogenous and isotropic in the simulation while in reality it has a skin and foam core that is not homogenous and therefore anisotropic with regard to its stiffness and strength. Thus the original assumption is not valid and a better procedure to analytically evaluate RPL structures is currently being developed. Figure 4 shows that the deformed pallet shape qualitatively matches the experimental observations.

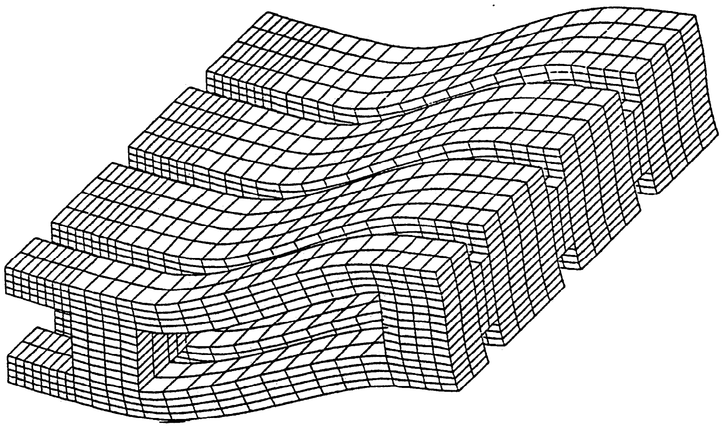

Figure 4. Finite element simulation of RPL pallet showing deformed shape

4.2 Field evaluation of RPL pallets

Six pallets fabricated to the design specifications were sent to DOE-Fernald for field evaluation. These were distributed among three locations within the site as follows: Location 1 – Production (5 pallets), Location 2 – Training (2 pallets), and Location 3 - Northstar (1 pallet). The evaluation conditions and findings are summarized below.

Location 1- Production: Three of the pallets were used at this production location where the pallets would be exposed to radiation. The three pallets were in a racked 'static load' configuration with four 55-gallon drums on each pallet. The material in the drums was Mag Flouride and the pallets were placed outdoors on a concrete floor. The total load on the bottom pallet was 9006 pounds (4094 kg.) and was sustained for five weeks.

Location 2 - Training: The training facility was supplied with two pallets and were subjected+ to 'dynamic loading', that is, they were used to move drums from one place on the location to another using fork trucks. The facility used to train operators of forklifts subjected the pallet to severe use with constant dragging and pushing of the pallets and the materials on it. Drums weighing about 4000 lbs were stacked and unstacked on these pallets routinely.

Location 3 - Northstar: The last pallet in the evaluation was used at this location for handling and moving 'dynamic' loads other than drums. The pallet was used to transport office equipment, desks chairs, etc. using fork trucks. The intent at this location was to study the pallet behavior under nonstandard loading configurations.

As indicated in the field performance reports [8], the pallets performed very satisfactorily at all three locations under a variety of loading configurations. There was no evidence of damage or cracks as a result of the sustained load. Apart from normal wear of the loading surface the pallet remained intact and no excessive deformation was noted at these usage levels. At the end of this period the top most pallet in Location 1 was removed from service and checked for radioactive contamination. No contamination was evident and the pallets were 'free-released'.

5 Life cycle cost analysis methodology

DOE-Fernald along with the Oak Ridge National Laboratories (ORNL) has developed a formal procedure for the life-cycle analysis of products and processes. This procedure provides a formal framework for evaluating the viability and economic feasibility of various options for a given process. This procedure detailed in [9 and 10] accounts for both tangible and intangible factors that affect various options for recycling and disposal at DOE sites. Embedded in these procedures is the LCCA of various product options for a given application. This procedure was followed in conducting the LCCA for RPL pallets versus other options.

The basic definition for 'life-cycle cost' in the DOE [9, 10] methodology is as follows: life cycle cost include the direct, indirect, recurring, nonrecurring and other related costs incurred or estimated to be incurred in the design, development production, operation, maintenance and support of an asset throughout its anticipated useful life span and through final disposal. Revenues such as user fees and salvage receipts should be included as an offset to the cost. The steps in the LCCA were as follows:

1. Identify the alternatives: In the case of pallets at DOE-Femald the alternatives available were: wooden pallets, galvanized steel pallets, and, RPL pallets.
2. Identify the life-cycle duration for each alternative: Since DOE-Femald is on a lo-year shutdown plan, the time duration for pallet needs for this study is 10 years. The estimated value of the design life for the alternatives were as follows [8]:

Pallet Type	Design Life, years
Wood	2
Steel .	10
RPL	5

3. Identify the cost categories for each pallet type: Various categories of costs for each alternative are as follows:
   - Acquisition (Initial) Cost: The cost of purchasing new pallets are:
     Wood - $20
     Steel - $160
     RPL - $275
   - Maintenance and Repair: Based on experience, some assumptions need to be made regarding frequency of repair and the cost of each repair for the various alternatives. It is assumed that the wooden pallets with a design life of 2 years are not repaired and are disposed off. The metal pallets being robust may not need any repairs during the lo-year life. Some of the boards on the RPL pallets may need to be replaced once during its design life of 5 years. The cost associated with this repair is accounted for in the LCC of the RPL pallet.
   - Disposal or Recycling Cost at end-of-life: At the end of their useful life since they are 'suspect-contaminated' the wooden and metal pallet, had to be disposed off through the appropriate procedure for contaminated materials. The cost of these options was included

in the analysis. Since the RPL pallets are not contaminated by radiation, they can be disassembled and recycled or sold as is for reuse under free-release conditions.

4. Identify costs in each year: Depending on the design life, maintenance required or disposal alternative involved the costs during each of the 10 years is identified.
5. Identify discount rate: For a 1 O-year project the real discount rate, R, is 3.5 percent as specified by the Office of Management and Budget [11].
6. Calculate present worth using discount rate: The total cost for each year is reduced to a net present value (NPV) using the formula

$$\mathbf{NPV = (Cost\ for\ Year\ Y)/(1+R)^{Y}}$$

where R is the discount rate and Y is the year under consideration. The total NPV for all 10 years then provides a life cycle cost for the given alternative.

The NPV value for the three options for the lo-year period were as follows:

Pallet Type	LCC at NPV
Wooden .	$815
Galvanized Steel	$517
RPL	**$587**

As seen, even though the initial cost of RPL pallets was considerably higher than the wooden pallets (Item 3 above), over the duration of lo-years the RPL pallets have a lower LCC. The RPL pallets are directly competitive with the Galvanized Steel pallets as the LCC for the two options are within 25 percent (the limits set by DOE methodology) of each other.

The DOE methodology [9,10] calls for evaluating the various alternatives using a Decision Matrix which account for both LCC as well as other intangible factors such as local public acceptance, impact on environment, institutional preference and worker safety impact. When all these intangible parameters were taken into account the RPL pallet did become a preferred option from the viewpoint of a life-cycle economic analysis.

6 Conclusions to date

The major conclusions regarding the development of design guidelines for structural uses of RPL include the following:

1. A combination of laboratory, full-scale and analytical predictions are needed to establish design guidelines for RPL in structures,
2. The ASTM standards provide necessary but not sufficient information for developing performance based specifications,
3. Design criteria must account for the unique type of material behavior exhibited by RPL in order to take advantage of all its other features and benefits.
4. A life-cycle cost analysis is usually needed to evaluate the economic feasibility of optional products to justify the use of RPL in structures.

8 Future work

Future efforts to expand the case study and pilot project described above involves a multi-client partnership between, state governments, federal agencies and the private sector. This partnership, is being coordinated by Battelle and the Plastic Lumber Trade Association and is addressing methods to overcome the barriers to RPL in the structural marketplace. This is a three-year, three-phase study that focuses on major potential applications for RPL, namely outdoor residential decks, marine boardwalks and other structures, and material handling items such as pallets. For each of these applications optimized design guidelines, durability information, and a database of appropriate material properties is being developed. The results of this study will be presented at future meetings.

9 Acknowledgements

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10 References

1. Krishnaswamy, P. et al (1995) "A Review of the Manufacturing Processes and Characteristics of Recycled Plastic Lumber (RPL)," Final report from Battelle to the Environment and Plastics Institute of Canada, N00 1678 1 pp. 1 l-l 9 .
2. ASTM Standard D 611 l-97, (1997) Standard Test Method for Apparent Bulk Density and Specific Gravity of Plastic Lumber and Shapes by Displacement.
3. ASTM Standard D 6108-97, (1997) Standard Test Method for Compressive Properties of Plastic Lumber and Shapes.
4. ASTM Standard D 6109-97, (1997) Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastic Lumber.
5. ASTM Standard D 6112-97, (1997) Standard Test Method for Flexural Properties for Compressive and Flexural Creep and Creep-Rupture of Plastic Lumber and Shapes.
6. ASTM Standard D 6117-97, (1997) Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shapes.
7. McLaren, M.G., (1994) "Recycled Plastic Lumber and Shapes - Design and Specifications", Proceedings of the ASCE Structures XIII Congress, Boston.
8. Krishnaswamy, P. et al (1997) "Field Evaluation of Recycled Plastic Lumber (RPL) Pallets" Final Report from Battelle to the Ohio Department of Natural Resources, G002867, pp. 9-19.
9. Yuracko, K., P. Krishnaswamy, et al (1997) "Applying Life-Cycle Decision Methodology to Fernald Waste Management Alternatives," Proceedings of the DOE Pollution Prevention Conference XII, Paper 12.

10. Yuracko, K., Yearce, P. et al, (1997), Decision Methodology for Fernald Scrap Metal Disposition Alternatives, Report prepared by Flour Daniel Fernald and ORNL for U.S. DOE Fernald Environmental Management Project, DOE Internal Project Report.
11. U.S. Government Document (1997) Office of Management and Budget Circular No. A-94.

Information technologies and data formatting for the design life of buildings

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Abstract
The current information systems for data exchange and management, such as STEP and IAI, available in the international arena are currently unsuitable to allow the 'design life of buildings' process to be carried out. To allow this process to occur, an object-oriented approach needs to be taken for the manipulation of building component data. To each object or building component, specific attributes need to be attached that will allow the design life of the building to be calculated under a range of different environmental classifications. Additionally, possible maintenance techniques and frequencies also need to be attached to each construction-object to allow the design life to be achieved by selecting either the correct material or material/maintenance combination. If sufficient data is attached as detailed in the paper, optimisation of material selection and construction procedures can occur by utilising life cycle costing analysis.
Keywords: Design life, data exchange, information technologies, IAI, STEP, object orientation, CAD, life cycle costing.

1 Introduction

Information systems used in the architecture, engineering and construction (AEC) areas are developing rapidly, and the scenario has shifted from one where the data is used simply to plan buildings and reduce costs, to one where efforts are being made to utilise the vast amount of data and knowledge currently stored on the performance and degradation of construction materials. One area wishing to utilise this data and knowledge is an IS0 project on the design life of buildings (DLB) under the auspices of Committee TC59/SC3/WG9.

This committee is establishing the basic procedures necessary for the DLB process. However, for this to occur within the CAD environments currently available, an information management system is needed. An information system suitable for carrying out the DLB process, needs to meet a number of rigorous requirements.

- It needs to carry enough information and the correct algorithms to be able to calculate the effect of the environment on the building materials used. These algorithms must include the self-modifying effect that the materials can have on their own microclimate and the significant effect building orientation can have.
- It needs to be able to define maintenance schedules for different qualities of building materials installed under different environmental conditions, either by storing empirical data or by using degradation models for the materials.
- Life cycle costing methodologies must be able to be applied using the data to calculate the benefits of using either high performance materials with little maintenance or lower performance materials with better maintenance procedures.
- It needs to be flexible enough so that new knowledge and predictive systems for material performance and maintenance can be incorporated without destroying the structure that allows calculations based on current knowledge.
- The information must be fully portable between applications and be suitable for all users, such as designers and constructors, for use throughout the building lifecycle.

Information management and data exchange in AEC have not met these challenges and current developments in STEP [1] and IAI [2] are inadequate for this work because they address the data requirements necessary in AEC areas on an 'information model' approach rather than a 'functional model' approach, i.e. data for a material used in construction is static rather than being dependent upon the function for which it is used. To allow the DLB process to move forward rapidly, common specifications are necessary for the data requirements needed to calculate the design life of a building. In establishing these data requirements, IS0 TC59 must not adopt the dangerous position of being incompatible with the developments taking place worldwide in data interchange and interoperability. Conversely, current developments in world 'standardisation practice' need to design their architecture so that it will allow full integration of the necessary information needed in a DLB process.

2 Systems for data manipulation

2.1 STEP

In the Standard for the Exchange of Product Model Data (STEP), the term 'product data' is supposed to completely define a product for all applications over its expected life cycle. For a “design life' application this changes from design, through construction, operation, refurbishment and finally demolition. To be compatible with STEP, any methodology developed for DLB should use the descriptive methods group [3–5] which underpins the STEP standard. The next level in the STEP process is the 'integrated information resources' group (the actual STEP data models) which contain parts that are reusable by application protocols. The 'generic resource' in this group ('Part 45 – Materials [6]) should contain the information resources necessary for a DLB process – unfortunately at the moment it does not. At the top level of STEP, no application protocol (or data model) currently exists to describe the specific product data attributes necessary to undertake a DLB process, and no test methods have been defined to assess conformance. One application protocol that has been approved for development and may have an impact on the DLB process is Part 208 – Life Cycle Product Change Process. This application protocol may have implications in DLB calculations because 'life cycle costing' is an integral part of the overall DLB process.

In addition to shape representation, STEP can support a wide range of non-geometric data such as tolerance specifications, material properties and surface finish specifications [7]. It is expected that support for the DLB data would be detailed in Part 45 – Materials, which is at committee draft stage.

STEP possesses a rigid and mature architectural framework and consequently may not be able to easily meet the needs for applications such as DLB. This framework is currently more suited to a material property model used in relational databases and does not account for the functional relationships necessary in an object-oriented approach required for the DLB process. In this approach, an object used in the construction process needs to inherit some of its attributes or functions from the surrounding objects and the environment in which it is located. In this aspect, EXPRESS [4,5] may be suitable in that it supports inheritance and derived attributes functions.

2.2 IAI

The International Alliance for Interoperability (IAI) [2] is working in parallel to STEP to define industry foundation classes (IFCs) which will provide standard definitions for attributes associated with AEC entities, the structure and relationship between these identities, and standard formats for sharing attributes by static and dynamic exchange.

This will eventually enable interoperability between applications from different software vendors. Until October 1997, the domain required for the DLB process was not being addressed by IAI, who were looking at architectural design, HVAC engineering, design construction management and facilities management. Starting from October 1997, the IAI Australian chapter initiated an IFC project 'Performance attributes of materials for design' in the IFC Release 3 time frame (1997-2000). The project aims at identifying typical industry practice in materials selection, based on performance factors (e.g. environment, service life and life cycle cost), thus expanding the existing IFCs to include material properties that can be used across domains. The IAI Australian chapter will take up the concerns of the DLB process, which may involve an analysis of the current objects in both the IFC and STEP cores. For example, a column in the IFC model is a base unit and if it is made from concrete, it is composed of aggregate, sand, cement, water, processing aids and possibly fly ash. If this column is exposed externally, its durability is critically dependent upon the proportion and quality of these individual elements and the exposure environment.

2.3 Lexis

Both STEP and IAI define the data exchange protocols necessary in the AEC area. They do not fully define the suite of objects necessary for the DLB process nor the necessary attributes or functions that need to be attached to these objects to allow the process to be carried out. One development which may eventually provide a solution is Lexis [S], which proposes a language comprised of the range of objects neccessary for the total construction process. These objects can be distributed into views as necessary to reflect the management process required of the data, as shown in Figure 1.

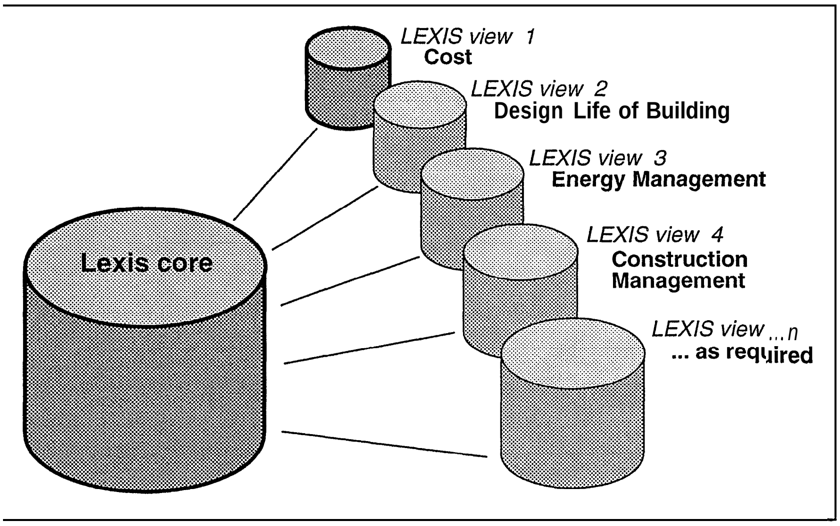

Figure 1. Lexis core and some possible views of this core

3 A system for the design life of buildings

The principle behind the DLB concept is to define the required design life for the building. Standard component lives are then allocated depending on their ease of accessibility. This process can be arbitrary as in the current IS0 TC59/SC3/WG9 document, established by legislation as in the New Zealand Building Code, or established in association with building product manufacturers. Once the standard component life is identified, the estimated component life can be calculated from:

$$ESLC = DLC \times A \times B \times C \times D \times E \times F$$

where ESLC = estimated service life of component, DLC = standard service life of component, A = quality of materials, B = design level, C = work execution level, D = environmental conditions, E = in-use conditions, and F = maintenance conditions, and the factors A-F vary from 0.8 to 1.2 depending upon the severity of the agent.

This approach is very simple and easily allows the expected service life of any individual component to be calculated. In a construction system, there are many thousands of individual components, with different expected lives, operating under different environmental, maintenance and operating conditions. Consequently, whilst the above simple approach may be suitable for individual components, for a computerised approach it would prove extremely cumbersome.

In utilising the concept used in the Lexis core language, the principle of an object-based scheme with attributes attached is the most workable scheme for the definition of the requirements to allow a DLB information storage and retrieval scheme to proceed, these objects being sorted into views depending upon the function or process being assessed. Hierarchical classification systems such as that proposed in Uniformat [9,10] may not be applicable, or if used would need significant modification, whilst the base documentation proposed in IS0 6241 [11], as shown in Figure 2, is applicable in that it divides the building up into the functional performance requirements (facade, electrical, services etc.). Subclassifications proposed in hierarchical systems such as these would need to be modified to meet an object-orientated approach – it may be easier to do away

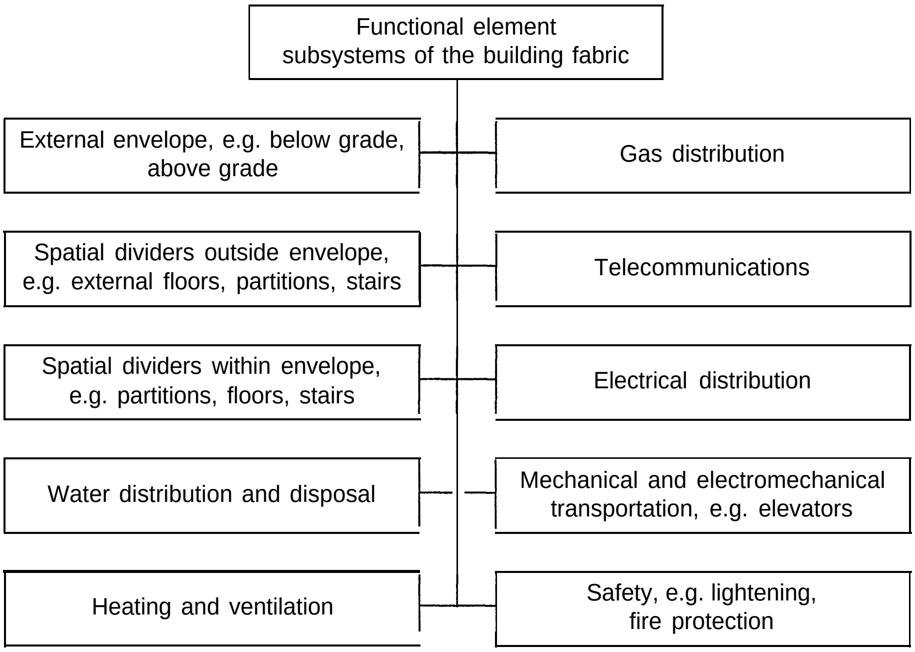

Figure 2. Building functional operations

with subclassification systems altogether and define the requirements of each object by a set of attributes, such as environment, maintenance, life cycle analysis and material performance, each being varied depending upon its functional application.

As well as allocating a range of attributes to construction-objectssuch as a door, the interaction of construction-objects is a critical factor for the DLB, e.g. dissimilar metals can corrode quickly and cause rapid degradation and shortened life. These relationships between objects have been discussed by Woestenenk [12] and some of these concepts, such as the interaction between spaces and boundary construction-objects, objects comprising part of larger objects, objects encountering each other and one object servicing another, are critical factors which have to be considered and included as necessary attributes to be attached to each construction-object.

3.1 The object approach

To develop a system to allow the DLB to be established, functional operations such as maintenance, refurbishment, demolition, thermal performance, acoustic performance and quantity estimation need to be considered.

Although these functional operations could be considered separately, they are considered together because each is controlled by material selection, degradation and the environment to which it is exposed. Additionally each may interact with another and modify each other's performance. Consequently a range of attributes needs to be attached to each construction-object as detailed in Appendix 1, with these attributes calculated from information stored in a range of libraries as detailed in Appendix 2.

Each of the attributes attached to the construction-object is required to allow the performance of the object in the building to be assessed, as well as to allow an adequate description of the object as its situation changes during the construction process. Once the object's environment is known, the performance of an object under the influence of this environment can be prescribed, either empirically or by means of degradation, life cycle or maintenance models. If the calculation is by a degradation model, then only the information specified in Appendix 2 is necessary. If the methodology is to utilise empirical data, supplied either by the object manufacturer or gathered from the field, then information for each environmental attribute is needed. Some of the essential attributes required for calculation of the DLB are expanded below.

4 Environmental attribute

In essence, there are three types of environments in a building, defined as:

- The external surface environment, which is the external macroclimate modified by the building surface to give a microclimate. This would include an envelope around the exterior of the building and would include below-ground and above-ground components and would take the building orientation into account.
- The inside building envelope environment, which includes the internal microclimate in the subfloor, wall cavities and roof spaces. This microclimate is heavily influenced by the external environment as well as the internal environment.
- The internal climate environment, which includes both internal living spaces and spaces between internal features such as internal wall cavities, internal first floor or above-floor spaces.

Definition of a construction-object's climate according to these three environments is currently difficult due to a lack of information. However, this may become possible as more information and more sophisticated prediction techniques are established to allow prediction of indoor and microclimate environments from external weather data.

In the meantime, it may be simplest to classify environments into broad categories with respect to the degradation factors affecting the major building components for both above-ground and below-ground applications. The principle is simple – an environment is classified in terms of its climatic factors such as temperature, rainfall, humidity, and the type and extent of pollution source. Additionally, UV needs to be defined for above-ground use to accommodate materials with different UV sensitivities. The importance of the various factors will vary for different types of construction-objects and where these objects are used in relation to the orientation of the building. There are also specific environmental factors that affect the degradation of particular objects but these are not considered in this discussion, although they will need to be discussed and included as the lifetime calculation models become more sophisticated.

5 Environmental Classification

A range of climate variables are necessary to define the aggressiveness of the environment. Some parameters relate directly to degradation, whilst others control the processes that promote degradation. The main factors affecting the environmental classification and thus the rate of degradation of construction-objects are time of wetness (on a metal plate), annual rainfall, surface equilibrium moisture content, extreme temperature, relative humidity, total global radiation and UV irradiance.

5.1 Climatic classification

It is proposed that climate be divided into four main classifications – dry, sub-humid, hurnid and very humid – and in turn these classifications may have a number of subsets as detailed in Table 1.

Class (abbreviation)	Subclass (abbreviation)	Examples
Dry (D)	Cold (C)	Icecaps, tundra, subartic
	Temperate (T)	Argentina desert
	Hot (H)	Australian desert
Sub-humid (S)	Cold (C)	Edmonton, central Canada
	Temperate (T)	European steppe
	Hot (H)	Central Queensland
Humid (H)	Cold (C)	Victoria, Canada
	Temperate (T)	Central east coast of Australia
	Hot (H)	Allahabad, India
Very humid (V)	Cold (C)	—
	Temperate (T)	Tokyo, Japan
	Hot (H)	Darwin, Australia

Table 1. Climate classifications

To establish the separate classes, a number of arbitrary decisions have been made and these may need slight modification to cope with the range of worldwide climatic conditions. The definitions are as follows:

- Dry – rainfall <400 mm per year or average 9 a.m. RH <50%.
- Sub-humid – rainfall 400–800 mm per year or average 9 a.m. RH >50% and <70%.
- Humid – rainfall 800–1300 mm or average 9 a.m. RH >70% and <80%.
- Very humid – rainfall >1300 mm or average 9 a.m. RH >80%.
- Cold – $AMM_{min}T$ <–5°C for more than two months of the year. Alternatively, $AMM_{max}T$ for the hottest month is <10°C.
- Temperate – $AMM_{min}T$ <–5°C for no more than one month and $AMM_{max}T$ >35°C for no more than one month.
- Hot – $AMM_{max}T$ >35°C for more than one month of the year.

$AMM_{min}T$/$AMM_{max}T$ are average monthly minimum/maximum temperatures.

In addition, the effects of total global radiation/UV radiation need to be considered separately as they do not easily fit into the above climate classification system.

5.2 Pollutant classification

Degradation of building materials due to pollution requires the determination of a number of factors such as airborne pollutant level (SO_x), airborne salinity, rain acidity, rain-ionic content, relative frequency of salt deposition/rain events, relative frequency of high pollutant/rain events, average wind speed and extreme wind speed. Incorporation of all these factors into a pollution classification scheme is complex. One such scheme where the pollutant classification depends upon the pollutant level and source is:

- Severe marine (SM) – airborne salinity exceeds a daily average of 300 mg/m^2.day.
- Marine (M) – average daily airborne salinity is between 60 and 300 mg/m^2.day.
- Severe industrial (SI) – airborne SO_x level exceeds 200 mg/m^2.day.
- Industrial (I) – airborne SO_x level is between 60 and 200 mg/m^2.day.
- Severe industrial and marine (SI+SM) – airborne salinity exceeds 300 mg/m^2.day and SO_x level exceeds 200 mg/m^2.day.
- Light marine or industrial (I) – either (a) airborne salinity is 15–60 mg/m^2.day, (b) airborne SO_x is 10–60 mg/m^2.day, or (c) rain water pH <5.5.

- Benign (B) – airborne salinity <15 mg/m^2.day ***and*** airborne SO, <10 mg/m^2.day ***and*** rain water pH >5.5.

Other specialised categories of pollutant may be included in given localities where geothermal, salt lake or soil contamination abnormalities exist.

5.3 Combined classification

A matrix of environments can be established by combining the climate with its subclass versus the pollutant source. The environment can be identified by a three-figure number where the first number defines the pollutant sources (severe marine and severe industrial (SM+SI = 1) to benign (B = 9)), the second defines the major climatic class (1 for dry to 4 for very humid), and the third defines the subclass (1 for cold to 3 for hot). For certain materials, it is essential to expand this matrix to take into account UV with a fourth number, varying from low (UV = 1) to high (UV = 3), where low is <14.4 MJ/m^2/day, medium is between 14.4 and 19.8 MJ/m^2/day and high is >19.8 MJ/m^2/day.

As shown in Table 2 (which only shows examples for a dry climate), a classification of 2-l-3-3 would signify an environment that is both severe marine and industrial, situated in a dry hot climate with high UV.

	SM+SI	SM+I	M+SI	M+I	SM	M	SI	I	B
DC-L	l-l-l-l	2-l-l-l	3-l-l-l	4-l-l-l	5-l-l-l	6-l-l-l	7-l-l-l	8-l-l-l	9-l-l-l
DC-M	l-l-l-2	2-l-l-2	3-l-l-2	4-l-l-2	5-l-l-2	6-l-l-2	7-l-l-2	8-l-l-2	9-l-l-2
DC-H	l-l-l-3	2-l-l-3	3-1-1-3	4-l-l-3	5-l-l-3	6-l-l-3	7-l-l-3	8-l-l-3	9-l-l-3
DT-L	1-1-2-1	2-1-2-1	3-1-2-1	4-1-2-1	5-1-2-1	6-1-2-1	7-1-2-1	8-1-2-1	9-1-2-1
DT-M	l-l-2-2	2-l-2-2	3-l-2-2	4-l-2-2	5-l-2-2	6-l-2-2	7-l-2-2	8-l-2-2	9-l-2-2
DT-H	l-l-2-3	2-l-2-3	3-l-2-3	4-l-2-3	5-l-2-3	6-l-2-3	7-l-2-3	8-l-2-3	9-l-2-3
DH-L	1-1-3-1	2-1-3-1	3-1-3-1	4-l-3-1	5-1-3-l	6-1-3-1	7-1-3-1	8-1-3-1	9-1-3-1
DH-M	l-l-3-2	2-l-3-2	3-l-3-2	4-l-3-2	5-l-3-2	6-l-3-2	7-l-3-2	8-l-3-2	9-l-3-2
DH-H	l-l-3-3	2-l-3-3	3-l-3-3	4-l-3-3	5-l-3-3	6-l-3-3	7-l-3-3	8-l-3-3	9-l-3-3

Table 2. Matrix classification system for environmental data

5.4 Catastrophic events classification

The classification of a catastrophic/special hazard event or area is a difficult factor that has received significant attention in recent years and has resulted in significant changes to national building codes. Some of the factors that need to be considered include frequency of hailstorms, flood risk, cyclones, earthquakes and geothermal hazard.

5.5 Climatic parameters

The above parameters can be used to characterise some but not all of the degradation mechanisms affecting buildings. In general (except for the hazard parameters) they are applicable to external building components. In some areas, information on all of the degradation factors may not be available, in which case it may be possible to predict these factors from general climatic parameters.

The prediction of a hazard for a component within the building envelope is more complex and in general can only be estimated by some type of transfer function which considers the relevant external and internal environments, the building design and the relevant material characteristics. This paper will not define the transfer functions and development of these functions, but it should be emphasised that the development of these functions is a critical factor allowing the DLB process to occur for building components that are not exposed directly to the external environment.

6 Life Cycle Costing and Maintenance Attributes

Maintenance is defined as ‘all actions necessary for retaining an asset in, or restoring it to, its original condition’ [13]. Clearly the scope of the asset referred to in the definition identifies to some extent what should be included or excluded from maintenance in any specific case. Three types of activity, recognised as being distinct from maintenance, should be considered when calculating the life cycle costs of buildings. These are complete replacement of the item, rehabilitation to a new standard or new use, and cleaning.

For life cycle purposes, both complete replacement and cleaning carried out in conjunction with maintenance activities should be included, with only rehabilitation excluded. The timing and costs of maintenance, replacement and cleaning are needed for each item. Thus the life cycle details required are:

- Component items on whichdifferent maintenance, replacement and cleaning activities take place.
- Initial capital cost attributable to each item.
- Durability of each component item as a service life.
- Extent of maintenance, replacement or cleaning required.
- Cleaning and maintenance patterns or intervals.
- Cost of each maintenance, replacement or cleaning activity.

The component items are represented as instances of objects and must be separately identifiable at a level of detail which allows individual identification of the above details, i.e. object performance attributes 8-l 1 in Appendix 1. It could be argued that there should be a systematic elemental breakdown along the lines of the National Public Works Council elements and sub-elements [14], so that life cycle costs etc. can be categorised by recognised components of a building. If the Lexis [8] approach is taken, then objects can be classified into any group that is required.

The extent of maintenance, replacement or cleaning is determined by the rate of degradation and the minimum service life from a range of possible lives, e.g. given (predetermined), maintenance dependent and functional. The whole-of-life costs are reduced to a single life cycle cost of the object, possibly using standard discounted cash flow techniques. Whilst initial estimates of life cycle costs are deterministic, stochastic variations may be included to account for the possible variability in the future timing and costs by applying a distribution to each of the service lives and costs.

The library of information required to support the object performance attributes are more extensive (Appendix 2) and require additional details of the available cleaning and maintenance techniques, the labour, materials and plant necessary to carry out each maintenance, replacement or cleaning activity, and other information such as accessibility to the degraded item, and occupational health and safety precautions. There may even be a disposal cost of replaced parts or items. The library information on individual items needs to contain alternatives such as new construction, preventative maintenance and condition-based maintenance, but not all that data is required for all components, e.g. some components will require only one type of data and may have data in common with others.

The object-oriented database structure links particular components via a group type and available listings of data on relevant materials within each group to allow multiple access and minimal data, e.g. new construction will have a number of subgroups within it, such as metal cladding, concrete cladding, tile roof and metal roof, each of which has data on the five sub-items listed in the table.

Discounted cash flow calculations also require annual cost escalation rates (actual or differential real terms) to allow for changes in costs or improvements in maintenance, replacement or cleaning techniques so that the most cost-effective life cycle approach can be ascertained. The life cycle costs can be estimated at either the object or multiple object level. The discounted life cycle costs will be used to determine the best life cycle strategy including whether material will be totally replaced or just repaired.

7 Conclusions

At the time of writing, current protocols and data formatting techniques in STEP and IAI are not sufficient to allow the object-oriented procedures required in a 'design life of buildings' process. To enable this process, a range of attributes needs to be attached to construction-objects. These attributes covering the climatic and life cycle processes will allow calculation of the design life, and the maintenance schedules necessary to achieve this life.

8 References

1. IS0 (1994) IS0 10303: Standard for the Exchange of Product Model Data (STEP).
2. Industry Alliance for Interoperability (1997) Industry Foundation Classes, IFC Project, Model Specification Version 1 .O.
3. IS0 (1994) IS0 10303-l : Industrial Automation Systems and Integration – Product Data Representation and Exchange: Part 1 – Overview.
4. IS0 (1994) IS0 10303-l 1: Industrial Automation Systems and Integration – Product Data Representation and Exchange: Part 1 1 – Description Methods: The EXPRESS Language.
5. IS0 (1995) ISO/TR 10303-12: Industrial Automation Systems and Integration – Product Data Representation and Exchange: Part 12 – EXPRESS-I Language Reference Manual, 10 December.
6. IS0 (1995) ISO/DIS 10303-45: Industrial Automation Systems and Integration – Product Data Representation and Exchange: Part 45 – Integrated Generic Resources: Materials.
7. Wellington, J. and Smith, B. (1995) IS0 TC 184/SC4 Reference Manual, NISTIR 5665.
8. Leslie H., January, M. and McKay D. (1997) Lexis Cost -A Cost Management View of Building and Construction, CSIRO Building, Construction & Engineering (draft).
9. Uniformat II (1992) A Recommended Classification for Building Elements and Related Sitework, NIST Special Publication 84 1, Gaithersberg, USA.
10. NATSPEC Classification, NATSPEC Pty Ltd, Milsons Point, NSW, Australia.
11. IS0 (1984) IS0 6241: Performance Standards in Building: Part 2 – Principles for Their Preparation and Factors to be Considered.
12. Woestenenk, *K.* (1997) *An Information Framework for the Construction Industry*, STABU Foundation, The Netherlands, ISBN 90.5 156.012-5.
13. Milton, H.J. (ed.) (1994) *Glossary of Building Terms* (4th edition), National Committee on Rationalised Building, Standards Australia and Suppliers Index, Sydney.
14. National Public Works Conference (1977) *Cost Control Manual – Standard Elements and Sub-elements,* National Public Works Conference, Canberra.

Appendix 1 Attributes for complete object definition

Construction-object	Door etc.	
Global properties		
1. Building shape and orientation	Latitude and longitude Shape Rotation of the major axis from the north (°)	
2. Quality of labour	Skilled or unskilled	
Description and properties		
1. Physical characteristics	Composition, dimensions etc.	Parts, material
2. Placement characteristics	Construction/assembly	Resource requirement, handling, storage, erection, installation, access and fixing techniques
	Maintenance and repair	
3. Capital costs		
Object performance attributes		
1. Functional application	External envelope, external spatial divider, internal spatial divider, water distribution, heating and ventilation, gas distribution, telecommunications, electrical distribution, mechanical and electromechanical transportation, safety	
2. Relationship with adjacent object	Space, object bounding space, connected, part of, servicing etc.	
3. Macro- or microclimatic classification	**Above ground**	
	Dry	Cold, temperate, hot
	Sub-humid	Cold, temperate, hot
	Humid	Cold, temperate, hot
	Very humid	Cold, temperate, hot
	Global radiation	
	Ultraviolet radiation	
	Below ground	
	Water table level	Water pH
	Soil type	
	Anerobic	
	Aerobic	
4. Pollutant classification	Severe marine, marine, severe industrial, industrial, benign, special	
5. Catastrophic classification	Flood, cyclonic, seismic	
6 Operating environment	Severe, medium, light	
7: Defined service life	Given life Maintenance-dependent life Functionality life Economic life Usage life Obsolescent life Calculated service life	
8. Maintenance and repair	Rate of degradation Cleaning and servicing intervals Costs per cleaning and service Resource requirements per maintenance activity Costs per maintenance activity	
9. Refurbishment	Repair and replacement resource requirements per activity Costs per repair and replacement activity	
10. Demolition	Resource requirements	
11. Life cycle costs	Cost and discounted cost per object	

3. Climatic classification		Time of wetness Rain acidity Rain ionic content Annual rainfall Relative frequency of salt deposition/rain event Relative frequency of high pollution/rain event Surface equilibrium moisture content Extreme temperature RH/extreme RH Total global radiation UV irradiance
4. Pollutant classification		Airborne salinity Airborne pollutants level (SO_x) Other
7. Defined service life		
8. Maintenance and repair	Cleaning	Cleaning technique Cleaning – labour Cleaning – materials Cleaning – plant Access technique
	Preventative maintenance	Maintenance technique Maintenance cost Maintenance periodicity Preventative replacement cost Preventative replacement periodicity Condition-based maintenance cost Condition-based maintenance periodicity Consequential maintenance costs Safety precautions – inspections Safety precautions – systems maintenance Safety precautions – system cost
9. Refurbishment		Refurbishment costs Refurbishment periodicity Refurbishment – labour Refurbishment – plant Refurbishment – materials Protective system Protective system costs Inspections Safety precautions
10. Demolition/removal/ disposal		Labour costs Plant costs Disposal costs Safety precautions – inspections Safety precautions – system maintenance Safety precautions – system costs
11. Life cycle costs		New construction cost Discount rate Escalation rates – labour Escalation rates – plant Escalation rates – materials Escalation rates – other

Energy Related Environmental Impact of Buildings IEA Annex-31

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Abstract
The paper describes the role of Annex 3 1, which is a shared task project supported by 14 of the countries that are members of the International Energy Agency's Implementing Agreement on Energy Conservation in Buildings and Community Systems. Its membership comprises government, academic and private sector researchers who have an expertise in how to evaluate the direct and indirect impact that buildings have over their full life cycle, on their interior, local, regional and global environments. Each participating country is to use an evaluation tool of its own choosing to assess the environmental impact of two simple reference building designs. The results will then be reviewed. Other evaluation cases that serve to illustrate particular merits of assessment methods will be included in the report. Additionally, it will have a section on the theory of Life Cycle Analysis, as it applies to buildings; a resources section comprising a classification and description of the numerous methods and data bases that have been developed, or are in the course of being developed and the last section will provide a reference and glossary. Additionally the potential to directly infuse results of the work into university curricula is being explored.

Keywords: buildings, energy, environmental impact, IEA

1 Introduction

Though it differs from country to country, buildings use about 30% of total energy directly, but when the indirect use is included closer to 50%(l). It is self evident then that their impact on the global environment is equally profound. The resolutions of the Kyoto conference are cause enough for concern in many countries as to how the goals can be met, but, as could well happen, that long before 2010 arrives the CO_2 reductions are deemed not to be sufficiently stringent, then all aspects of the economy will be stretched to find the most efficient ways to reduce energy demand, especially fossil fuels. It is vital that endeavours to reduce green house gas emissions do not become such an absorbing issue that others, such as water use efficiency, are not put into proper perspective. There is need for procedures that help decision makers answer the question, "all things considered what is the most efficient way to reduce the environmental impact of a particular building?"

This question is being addressed by many groups in several countries. As a result there is a growing inventory of approaches to the issue; from sophisticated multifactored methods of analysis to simple user-friendly check lists. Since the priority is to consider environmental repercussions in the long run, so, for the most part, the work of the annex is concentrating on Life Cycle Analysis (LCA) methods. The role of the annex is described below in this section.

The energy and mass flows associated with many materials are well studied, especially for example packaging products, and consumer products such as beer. Such studies are challenging enough, but at least they have the benefit that the complete life is highly predictable. Not so with buildings. The life expectancy of buildings is usually highly unpredictable; it is not known how occupants will use or misuse a building; changes in technology, society, economics and the environment and above all, land values, will influence a building's future. Any attempt to evaluate the impact that a building has on the environment must acknowledge that over its life-cycle the majority of the causes and effects of buildings on the environment are going to be intangible. Notwithstanding these factors, it is vital that all those who make decisions regarding the future of buildings have access to tools that can point them to more environmentally benign solutions.

Since such a large proportion of our future building needs will, for better or worse, have to be met by the existing stock, any comprehensive consideration of the topic must deal as much with existing buildings as with new ones.

For tools to be effective they must be devised so they can be relevant to a specific building and location, use sufficiently current data and be credible, comprehensible and affordable for the user, be they a building official, architect or developer. Apart from the need for tools at the specific building level is the need to understand what is required at a macro level to change the characteristics of the building stock as a whole. This is the realm of the building industry and government. In response, the annex addresses the challenge of how to agglomerate the impact of defined sets of buildings or even the building stock of a nation as a whole, as well as to identify what technical changes would be required to make buildings greener.

The myriad of audiences is far too broad to address in one report. For example, each country has some uniqueness with respect to the way in which its building industry operates creating different professional groups. There are circumstances when a highly detailed analysis is called for, a role for an experienced analyst. In contrast, a small-scale building contractor or do-it-yourselfer hopefully would also like to know how to go about construction in a most responsible fashion, clearly a very different audience.

The final annex report is being written therefore to meet the needs of those who themselves develop tools for specific audiences, in their own languages, idiom and requisite level of detail.

The role of the IEA annex on the Energy Related Environmental Impact of Buildings is therefore to see that the greening of buildings is accelerated by improving the availability and relevance of design tools. This it will do by providing those who are devising them with the best source of information on the subject. To do that there will be three outputs from the annex:

- a report comprising four sections: theory, application, resources and glossary;
- a short document that sells the importance and benefits of LCA analysis, and;
- prospectively, the foundations of a university level course that will pass into the hands of a consortium of universities to ensure excellence in teaching on the topic beyond the life of the annex.

The annex comprises academics and private sector and government researchers from 14 of the countries (see section 7 for list of participating countries) who are members of the International Energy Agency (IEA), Implementing Agreement (IA) on Energy Conservation in Buildings and Community Systems. Other IAs focus on different aspects of energy use. Their function is to initiate annexes, or international task sharing projects, that typically complete their goal within 4 years.

The work of this annex commenced with collecting one page summaries of methods already developed or being developed in the participating countries. There was no attempt to be exhaustive, nevertheless some 50 methods were identified providing the participants with a overview of methods that have been devised so far. It made clear the rage of different approaches that can be taken and the challenge for a neophyte to determine which method offers the best match for given needs. In reality the choices are usually quite restricted, through language and the pertinence of the data bases, to 'methods developed in the region in question.

Initially the work of the annex was divided into 8 sub-tasks but is now reduced to five, each corresponding with a section of the report. As mentioned above these sections are: introduction, theory, application, resources, and references and glossary. The following sections provide a brief review of what these sections will cover.

2 Outline of planned Annex report

2.1 Introduction

The introduction will prove an overview of what environmental impacts of buildings are, why is it important to be able to evaluate them and how it is currently being done. It will put the subject into a context of reality, namely that many of the elements that affect the environmental performance of a building are beyond the influence of anyone specifying a building architect for example. Though he cannot know what the life expectancy of a building may be, he or she may be able to specify elements of a design that will increase a building's ability to adapt to changing technology and use. But to link a feature of adaptability to energy use, whilst possible qualitatively, is rather beyond our ability to do it quantitatively at least yet.

Of course whether a building gets specified one way or another is governed in most jurisdictions by first cost, with operating costs often taking a back seat. But if we can strive to develop reliable and sufficiently accurate tools that concurrently estimate capital costs, operating costs as well as life cycle environmental impacts then one is empowering the decision maker to explore options that are presently just not economic . to explore.

2.2 Theory

To help describe the scope of the annex and to clarify its boundaries and interrelationships of factors important to the study, liberal use will be made of diagrams.

Much of the language of LCA has already been established by various bodies, for example, SETAC (Society for Environmental Toxicology and Chemistry) and SPOLD (Society for the Promotion of LCA Development). Their pertinence, and concepts such as inventory analysis and environmental loading, are introduced and made relevant to the building sector. The distinction between environmental loading and impacts is also explained.

2.2.1 Human factors

The pre-construction process follows different paths in each country. Nevertheless one can generalize the fundamental steps taken. With each step it is possible to put a human face on the process; who does what, when, and what information does each person need at each stage. For example, where there are options with respect to where a building will be located, it is important to be able to evaluate weigh up, the environmental transportation impacts, not just based on current modes of transport, but to the degree possible, the modes that are likely to evolve over the foreseeable life of the building. This is only pertinent at the concept stage and so there is little point in cluttering up the tools an architect may use with transportation factors if he has no influence over them. Thus the design of tools best follows the stream of typical decisions and decision makers.

2.2.2 Physical framework

What physical components are accounted for? Directly, are the immediate surroundings, envelope, structure, mechanical and electrical systems and fit out. Indirectly, are the externality elements: infrastructure, power stations, mining operations that feed the building materials sector; a long, but relevant, list.

2.2.3 Tools, rules and methods

To describe the features of the many analytical methods available, and thus facilitate comparison, it has been necessary to establish a framework within which to describe these methods. This has been the most challenging aspect of the work of the annex because a comprehensive review becomes an enormously complex to the extent that the wood cannot be seen for the trees. Hence we have had to rationalize on a much simplified framework so that it remains understandable.

Types of energy, energy chains and the environmental loading associated with them are described. Understanding the energy chains is fundamental to understanding the energy return on energy invested for alternative energy sources. How much more energy might have to be embodied in the design of a building to improve its passive solar performance? If the power demand of a building can be reduced by 1 kW, how much embodied energy is saved in the energy supply system? These are the energy questions that can be addressed by at least some of the methods.

The stages at which energy is use during a building life cycle is described, namely from the mining or harvesting of raw materials and recycling of other materials through to the eventual disassembly of a building. Questions such as what are all the stages, which ones are trivial and which are most relevant are answered; bearing in mind that what is most pertinent in one building, place and time may be quite different from another building.

Generally the operating energy demands of a conditioned building dominate other energy uses. However, as buildings become increasingly energy operationally efficient, other factors, such as maintenance and embodied energy become more relevant.

The theory section goes on to describe the use of benchmarks, sensitivity analysis, aggregation methods and data sources.

2.3 Application and Demonstration

The aim of this portion of work is to:

- demonstrate available tools for assessment of energy related environmental impact of buildings;
- show how the tools lead to improvements;
- (indirectly) convince building industry of the usefulness of these tools.

To emphasize the importance of LCA methods it is necessary to illustrate that some of the outputs are not intuitive. For example, in a study on the embodied energy of a new house in Canada it was calculated that the most energy intensive material was the carpets and underlay, assuming they were changed every 10 years(2).

The work is being carried out in three steps:

- assess similar buildings in different climates by using different tools;
- analyse and report existing designs or buildings for which assessment tools have been used, and;
- report on conclusions and recommendations.

The “similar buildings” are two simple designs: an office and a house. For each building each country is to carry out an environmental assessment using a tool that has been developed in the country concerned. In addition to this structured comparison there will be a section of precedents, or cases; i.e. examples of assessments of buildings that illustrate the value of a particular way of conducting an assessment.

In this regard there are direct linkages between the work of this annex and that of the Green Building Challenge ‘98, so some of the cases presented may also be those chosen for GBC’98.

2.4 Resources

This section will be a classified compendium of information on the design tools and data bases that are currently available or are being developed.

2.5 References and Glossary

This section of the report will provide the building fraternity with several useful lists and a glossary. Included will be a listings of

- agencies, universities and research centres. who are actively involved in the subject;
- an alphabetic listing of abbreviations and acronyms;
- a glossary of terms that are pertinent to the subject, and;
- a section on benchmark values and conversion factors.

3 Other Annex outputs

3.1 Summary document

In addition to the primary report, the annex will publish a concise brochure/booklet that illustrates and promotes the use of tools to improve the design of buildings. This will be written in a jargon free manner.

3.2 Web Site

The Annex operates a web site <http://annex3 1 .tce.rmit.edu.au/iea/home.html> which it is using to share the results of its work.

3.3 Educational support

Many universities faculties, typically schools of architecture, include in their curriculum some teaching on the subject of the linkage between buildings and the environment. The linkages of global concern are, in principle, common to them all. The members of the annex therefore support the idea of enriching these courses with the common component of their curriculum. It may foster a "we are all in this together". frame of mind amongst the students knowing that others are sharing the same knowledge. To this end, and at the time of writing, the annex is in the process of exploring the creation of a critical mass of university departments that would collaborate with the annex on the creation of curriculum content of common interest. Interest is being shown from Australatia, Asia, North America and Europe.

4 Schedule

Though the substantive part of the work of the annex will be complete within 1998. Time allowance for editing and printing will mean that the final report will not be available until sometime in 1999.

5 Conclusions

The work of annex 31 will make available an invaluable source information for those who already have a familiarity with the topic or who are serious students. Because it is a fast moving topic the shelf life for a substantial component of the final report will be limited. However the theory section should establish itself as long-term reference point. The prospect of establishing a consortium of universities to collaborate in order to ensure excellence and breadth in teaching offers the prospect of some continuity of expertise embodied in the participants of the annex. .

6 References

(1) Unpublished communications within annex membership.

(2) Moffatt, S. *Optimize, A Method for estimating the Life cycle Energy and Environmental Impact* of *a House, CMHC* Report. To be available by the end of 1998.

7 Annex participants

Australia	France	Norway
Canada (Operating Agent)	Germany	Sweden
Denmark	Japan	Switzerland
Finland	Netherlands	United Kingdom
	New Zealand	United States

Weather-induced degradation of PVC profiles in Indian climate

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Abstract
Commercial PVC profiles were exposed to 7 years natural weathering and 3000 hours in accelerated weathering of UV exposure. The weathered profiles were evaluated in terms of emergence of surface topographic features, formation of degraded chemical species and loss in mechanical strength. SEM studies reveal that particle-induced blackening and white exudate deposits were the main weather-induced defects that appeared on the profile surface. The chemical species formed during outdoor and accelerated weathering exposure were very different as observed in diffuse reflectance spectra. Elongation data was used as an indicator for assessing the performance of PVC profiles under natural and accelerated exposure.
Keywords: PVC, weathering, UV exposure, degradation, elongation.

1 Introduction

Poly (vinyl chloride) is a low cost commodity polymer wed in rigid and semi-rigid formulations for various uses in buildings. It is reported that the consumption of PVC in buildings alone exceed 0.21 million tonnes (-80 % of total production) and is expected to continue to grow. PVC siding and profiles represent two of the more recent applications generating significant amount of commercial interest in buildings to replace conventional materials. However, the key concern is polymer stability under long term weathering with respect to property retention and aesthetics [1,2]. However, even small variations in the compounding formulations can lead to considerable changes in the ageing behaviour of PVC based materials. It has been estimated that roughly half of the annual tonnage of polymers are employed outdoors where performance can often be limited by weathering.

It is well known that PVC undergoes dehydrochlorination and photo-oxidative degradation upon exposure to outdoor environments. As a result of dehydrochlorination, PVC gradually becomes coloured, turning to reddish brown due to long chain conjugated polyene sequences, indicative of aesthetically objectionable performance fur sidings and profiles [3]. Subsequent rapid oxidation of polyene sequences leads to the formation of carbonyl and hydroperoxide groups that promote serious degradation and loss of physical properties via an autocatalytic free radical mechanism. In order to achieve long term weathering of PVC profiles, the present trend is to use an optimal level of recently developed new polymer additives alone and also in combinations to obtain synergistic effects in the formulation suitable to varying climates [4]. However, data on weathering performance of profiles based on these formulations is relatively unknown to users in tropical climates such as India. In the present paper, we report the performance of unplasticized PVC profiles in 7 years outdoor and 3000 hours in accelerated weathering exposures.

2 Experimental

Extruded UPVC profiles having thickness ranging from 2-2.5 mm were obtained from Indian manufacturers. The profile formulation contains PVC copolymer, organotin stabilizer, paraffin wax, calcium stearate, TiO_2 etc.

The UPVC samples were exposed to 7 years natural weathering mounted on fixed racks facing south at an angle of 45^0 to the horizon at Roorkee. Representative climatic data of Roorkee climate is given in Table 1. The samples were also artificially weathered for 3000 hours in a Xenotest-450 (Original Hanau-GmbH) in accordance with ASTM G-26 using a cycle of 102 minutes of *W* light at a black panel temperature of 35-40 °C and 18 minutes of *W* light and water spray at a black panel temperature of 25 °C. The specimens were drawn out periodically to measure various properties.

Table 1 Average climatic data of exposure site at Roorkee(India)

Climatic variables	Value
Max. mean annual tempera&	32 °C
Min. mean annual temperature	13.50 °C
Max. mean annual relative humidity	72%
Min. mean annual relative humidity	30%
Mean annual rainfall	1020 mm
Mean daily solar radiation	731 k cal / m^2 hr

The tensile properties of fresh and weathered profiles were determined according to ASTM D 638-74 at a cross head speed of 5 mm / minute. The reported results were the average of five tests. Surface topography of samples was carried out by scanning electron microscope (Phillips 501, Holland). Absorption spectra of fresh and exposed samples was also recorded by UV & Visible spectrophotometer (Perkin Elmer- 240) in diffuse reflectance mode.

3 Results and discussions

3.1 Micromorphology

The surface morphology of fresh and weathered samples in outdoor exposure is given in Figure 1 (a-d). Weathered surfaces showed discontinuity in surface in the form of particle-induced blackening, exposition and aggregation of particles and growth of microcracks. These defects appeared on the surface increase with the increase of exposure time. The phenomenon of blackening around sharp edge / aggregate particles could be explained on the basis of polyene formation by a zipper like elimination reaction of HCl. The exposition of particles near the surface indicates the erosion of surface due to weather-induced degradation. An interesting feature of white exudates due to migration of chemical constituents on the surface exposed to 3 years outdoor as reported earlier [5] can be seen in Figure lc. Thickening of these deposits was further noticed with extended periods of exposures (5-7 years) (Figure 1d). It is assumed that these exudates may sometimes act as a mechanical barrier protecting further degradation of the profile surface from solar radiation. Cracks / pits formed in the early stages of exposure are also filled with particles probably from the deteriorated and eroded surface itself.

Under accelerated weathering of W exposure (Figure 2 a,b), the deterioration of the surface is initiated with the formation of small blackish spots followed by its spreading and intensification. It is noticed that severe darkening is restricted only to aesthetics of profiles and little affecting the strength properties, as observed in the experiment. After 3000 hours exposure, surface roughness, white patches/ particle exposition and appearance of scattered, thread- like structure

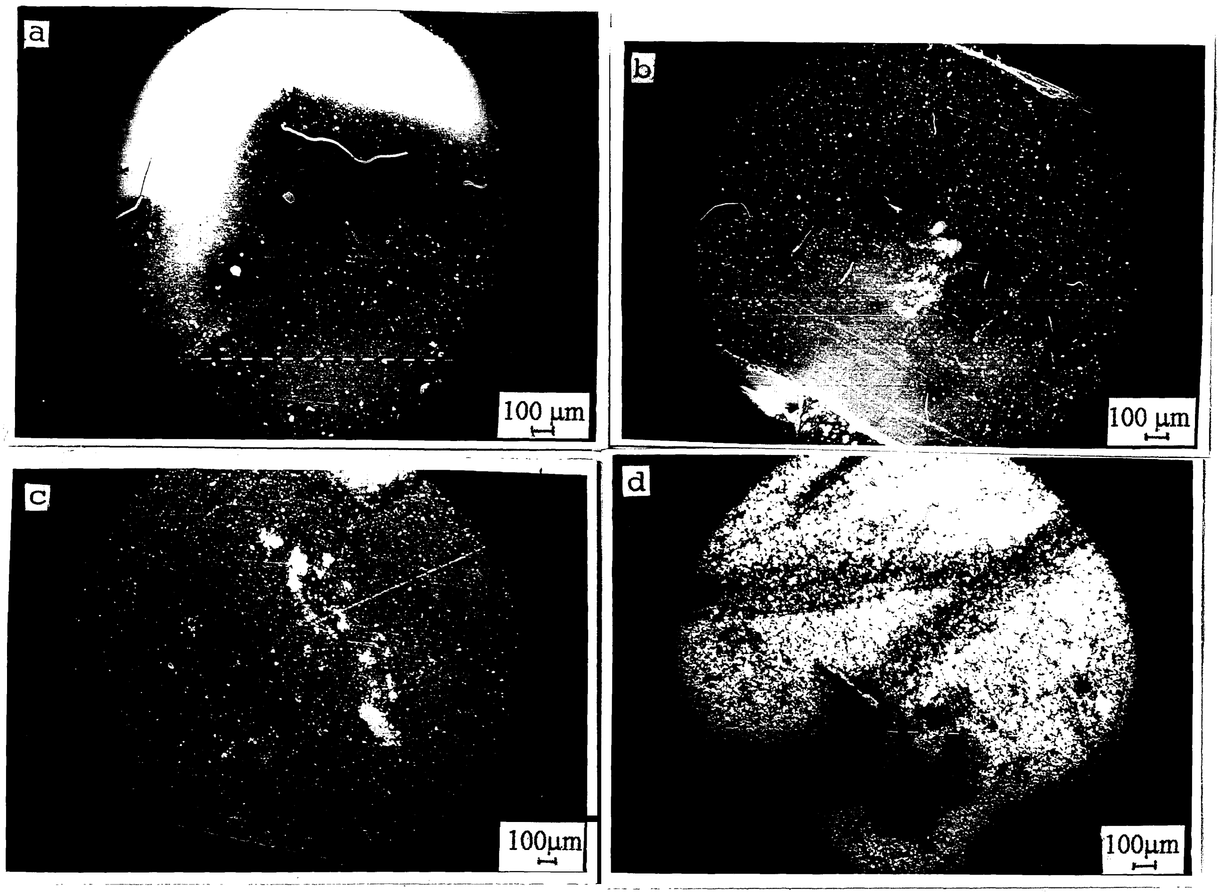

Figure 1 SEM of fresh and outdoor exposed PVC profiles (a) fresh (b) 1 year (c) 3 years (d) 7 years

surrounded by blackish area were observed. It can be seen that the extent of surface deterioration in 3000 hours exposure was microtopugraphically comparable to the 2-3 years outdoor exposure. However, the severity of the degradation was more pronounced in samples exposed to natural weathering.

3.2 Spectroscopic Studies

Figure 3 shows W & visible spectra of fresh and exposed PVC samples in diffuse reflectance mode. In accelerated weathering, there is an increase in the intensity of absorption bands at 300-330 nm whereas in natural weathering, the appearance of a new band at 220 nm and an increased peak intensity at 200 nm were observed. It is noticed that the formation of conjugated chromophoric groups increases with increasing exposure time. The shifting of absorption band towards the visible region in samples subjected to W exposure, results in darkening of the PVC. The peak at 300-330 nm is attributed to the formation of carbonyl /hydroxyl groups

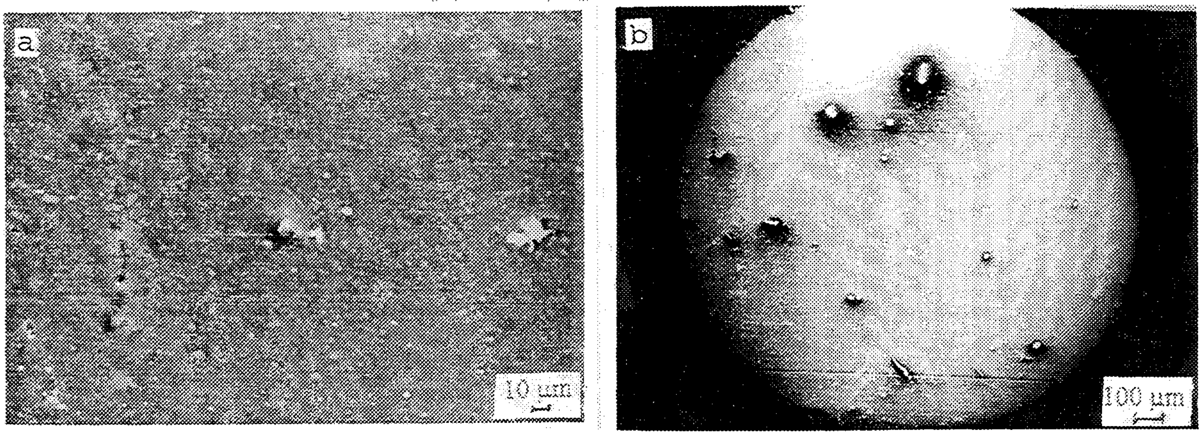

Figure 2 SEM of PVC exposed to accelerated weathering of UV exposure (a) 1000 hrs (b) 3000 hrs

(UV exposure) whereas the peaks at 220 and 200 nm are due to the conjugated carbonyl and carbon-carbon conjugated band sequence (natural exposure) respectively. Viewing the spectra, it appears that the PVC spectral sensitivity towards solar radiation and xenon arc UV are different. While recording IR spectra, the spectral changes in the intensity at 1730 cm^{-1}, 2925 cm^{-1} and broadening of 3600-3200 cm^{-1} region were noticed for both weatherings. The increase in peak intensity of different groups in exposed samples is the result of photo-oxidative degradation [6].

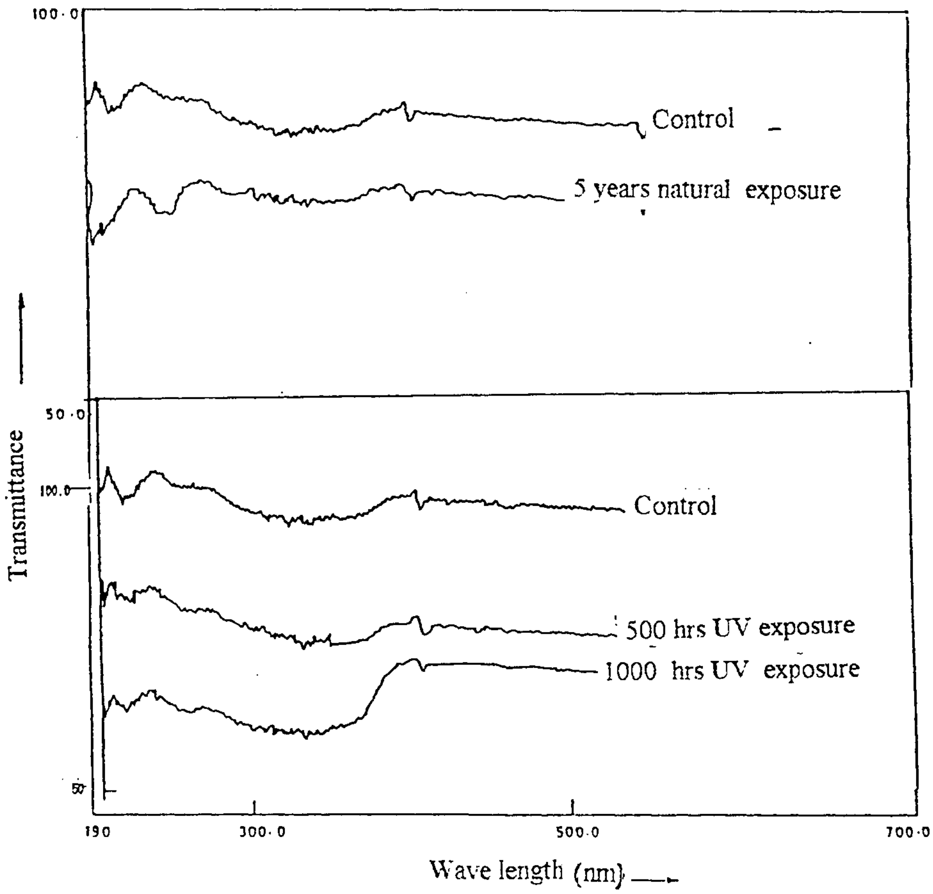

Figure 3 UV absorption spectra of fresh and exposed UPVC

3.3 Mechanical Properties

The tensile stress-strain diagrams of UPVC profiles under both weathering conditions are given in Figure 4. The samples exhibit a well defined yield drop followed by cold drawing showing shear yielding. The behaviour of curves of exposed samples was very similar to that of unexposed samples except that the elongation is reduced. The moderate decrease of tensile strength in outdoor exposure as well as in accelerated ***W*** exposure were observed. Elongation at break tended to be reduced drastically after exposure to both weathering conditions. Under outdoor exposure, there is a pronounced drop in elongation value up to lyear exposure and thereafter remains almost unchanged upon further exposure. On the contrary, a continuous decrease in the values of elongation was noticed in accelerated exposure. In the less steep portion of curve, the profile is already marked weathered and comparison is meaningless.

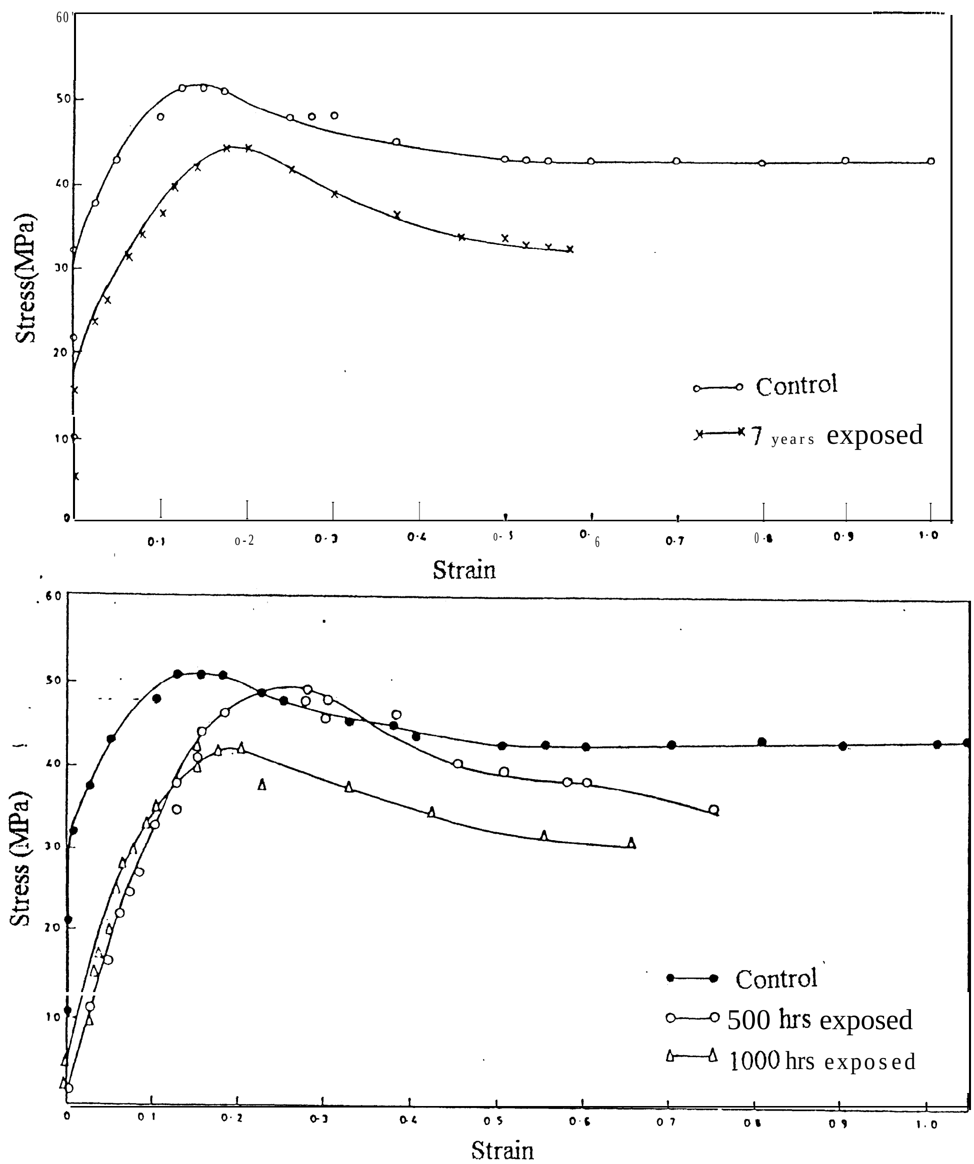

Figure 4 Stress-strain curves of fresh and exposed PVC sheet (a) outdoor exposure -7 years (b) accelerated W exposure -1000 hrs

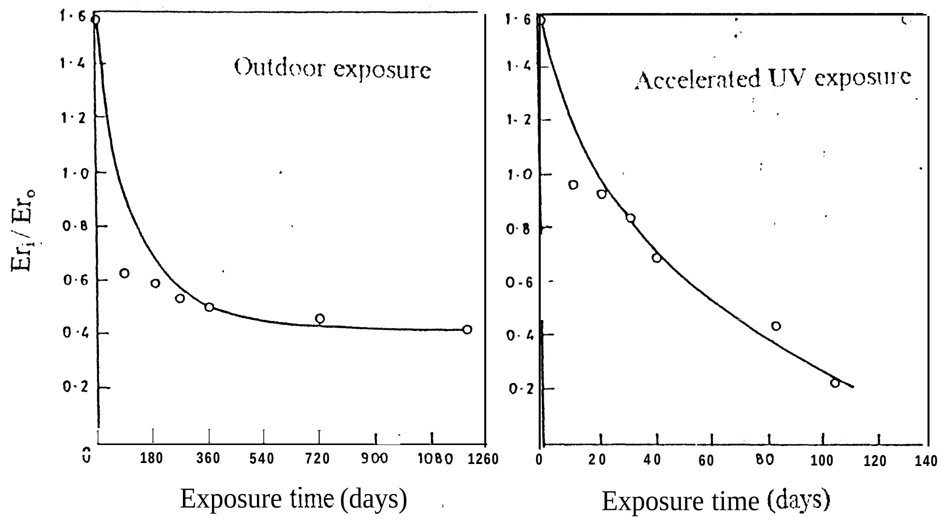

Figure 5 Ratio of Er_i / Er_o as a function of exposure time for UPVC sheet

As degradation process advances, surface flaws develop that serve as sites for stress concentration and hence centres from which mechanical failure can propagate [7].

A correlation between accelerated W and outdoor exposure is attempted on the basis of elongation data after various periods of exposure in particular because of its sensitivity towards exposure conditions. Figure 5 gives the values found for the ratio Er_i / Er_o where Er_i is the ultimate unit after time i of exposure to radiation and Er, is the same quantity for the material before exposure. It is roughly estimated that for these materials, 78 days in accelerated **W** is required to reach the Er_i/Er_o ratio of 0.40 (**1** year of natural exposure in Roorkee, India). More work is required to arrive at a definite conclusion.

4 Conclusions

The present studies have shown that weather-induced degradation causes extensive surface deterioration and impairment of mechanical properties under long term exposure conditions. Surface flaws induced by ***W*** radiation act as potential sites for the loss of mechanical properties especially elongation. For rapid introduction of these types of materials into the markets, the behaviour of new materials in actual use should be known to users for wider acceptance. Thus, more work is required to develop a technique for proper assessment of material performance in a very short period of time.

5 Acknowledgement

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6 References

1. **Davis, A. And Sims, D. (1983)** *Weathering* **of *Polymers*, Applied Science** Publishers, London and New York.
2. Braun, D (1975) *Degradation and Stabilisation of Polymers*, *G.* Geuskens, ed , Wiley, New York, p. 23.
3. Blaga., A. (1984) Effect of the environment on the durability of plastic-based materials, ***Materials and Structures***, Vol. **17,** pp **97-105.**
4. Mathur, K.K. And Vanderheiden, D.B. (1984) Precipitated calcium carbonate as ultraviolet stabilizers and **impact** modifiers in poly(vinyl chloride) siding and profiles, ***Polymer Additives,*** J.E. Kresta, ed, Plenum Press, New York and London, pp 371-389.
5. Blaga, A. (1972) Long-term. weathering can change the complexion of PVC, *SPE Journal*, **Vol.28, p.25.**
6. **Searle, N.Z. (1971)** ***Analytical Photochemistry and Photochemical Analysis,*** **J.M.** Fitzgerald, ed, Marcel Dekker, New York.
7. Chauhan , R. (1995) *Studies **on Photodegradation** of **Materials by Instrumental Techniques***, M.Phil Dissertation, University of Roorkee, Roorkee.

Information System for Maintenance of 2500 Buildings: A Case History

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Abstract
In 1994, the Texas Legislature passed a rule that required all state agencies to have no more than 153 square feet of office space per employee. Each agency was to survey its space and determine whether or not it complied. The Texas Department of Transportation (TXDOT) also chose to determine the physical condition of its facilities including the structural system and the estimated cost to maintain its facilities. The cost determination was to include immediate repairs and replacements which were defined as those required within two years and longer term costs over the following 28 years.

TXDOT has more than 2500 buildings of several types at more than 500 locations spread throughout the entire State of Texas. TXDOT chose to have the results of its survey compiled into a database system so that all of the physical condition information could be retrieved easily. This was also to provide the basis for a future facility management system which would aid maintenance decisions.

The methods use to inspect the buildings and catalog the conditions are presented. A condition rating system was developed to allow comparison of different systems, conditions, and building types. Service life aging curves were developed in order to predict when repairs, maintenance, or replacement would be necessary. cost estimates for the repair, maintenance, and replacement were also developed. Reports comprising 54 volumes and several feet of shelfspace were prepared from the database which was estimated to contain more than 1.5 million points of data. An Executive Summary report was also prepared from the database. All data are available in the database for future analysis.
Keywords: cost estimates, database, maintenance, management system, rehabilitation, repair, replacement, service life.

1. Introduction

In 1994, the Texas Legislature passed a rule that required all state agencies to have no more than 153 square feet of office space per employee. Each agency was to survey its space and determine whether or not it complied [1,2]. The Texas Department of Transportation (TXDOT) also chose to determine the physical condition of its facilities including the structural system and the estimated cost to maintain its facilities. The cost determination was to include immediate repairs and replacements which were defined as those required within two years and longer term costs over the following 28 years.

TXDOT has more than 2500 buildings of several types at more than 500 sites spread throughout the State of Texas. These buildings and sites are managed by 25 District Divisions under the overall supervision of the Headquarters Division. The types of space in these buildings include office, laboratory, warehouse for equipment and materials storage, vehicle maintenance, and rest area facilities along various highways. The total space in the buildings encompassed more than seven million square feet.

An outside consultant was retained by TXDOT to aid with the condition assessment survey and cost estimation. The scope of the project involved collecting quantitative data (system type, size, materials,, quantity, etc.), identifying deficiencies, establishing numerical condition rating systems, and estimating remaining service lives of systems, and establishing estimated repair, rehabilitation, and replacement costs. The assessment format and criteria, basis for evaluation and recommendations, and cost estimating methodology were documented. The data and information obtained were placed in a computer database which will become part of a planned future overall facilities maintenance management system for all of the facilities of TXDOT.

2. Conceptual maintenance management system

Maintenance management systems for any type of facility can be conceptually defined as shown in Figure 1. The first module is an Inventory Database which identifies all of the elements to be managed and contains the basic information for each element. Information concerning location, use, components, types of materials, and ages are stored in the database. The second module is the Condition Index System which allows the current condition to be quantified as a numerical rating based on the objective measurement of critical parameters. For items such as roofs, the critical parameters include defects such as blisters, splits, wrinkles, open flashing, etc. The Condition Index System must have the ability to also predict the future condition. This is necessary in order that plans for future repairs, rehabilitation, or replacement can be formulated. The module must also have the ability to store, retrieve, and analyze past condition information, if available, in order to improve predictions of future condition.

The third module is the Maintenance Policy System. This allows the owner to specify certain actions when specific sets of conditions occur or are predicted to occur. The fourth module is the Maintenance Priority System that ranks the various elements in terms of their importance relative to the fulfillment of the missions or needs of the owner, operator, or user of the facility. A warehouse in which paper products or an office building with computer operations on the top floor would likely require a higher priority than a warehouse in which unwrapped plastic pipe is stored. This allows the owner to allocate limited budgets in an optimum manner consistent with the importance of each element or component.

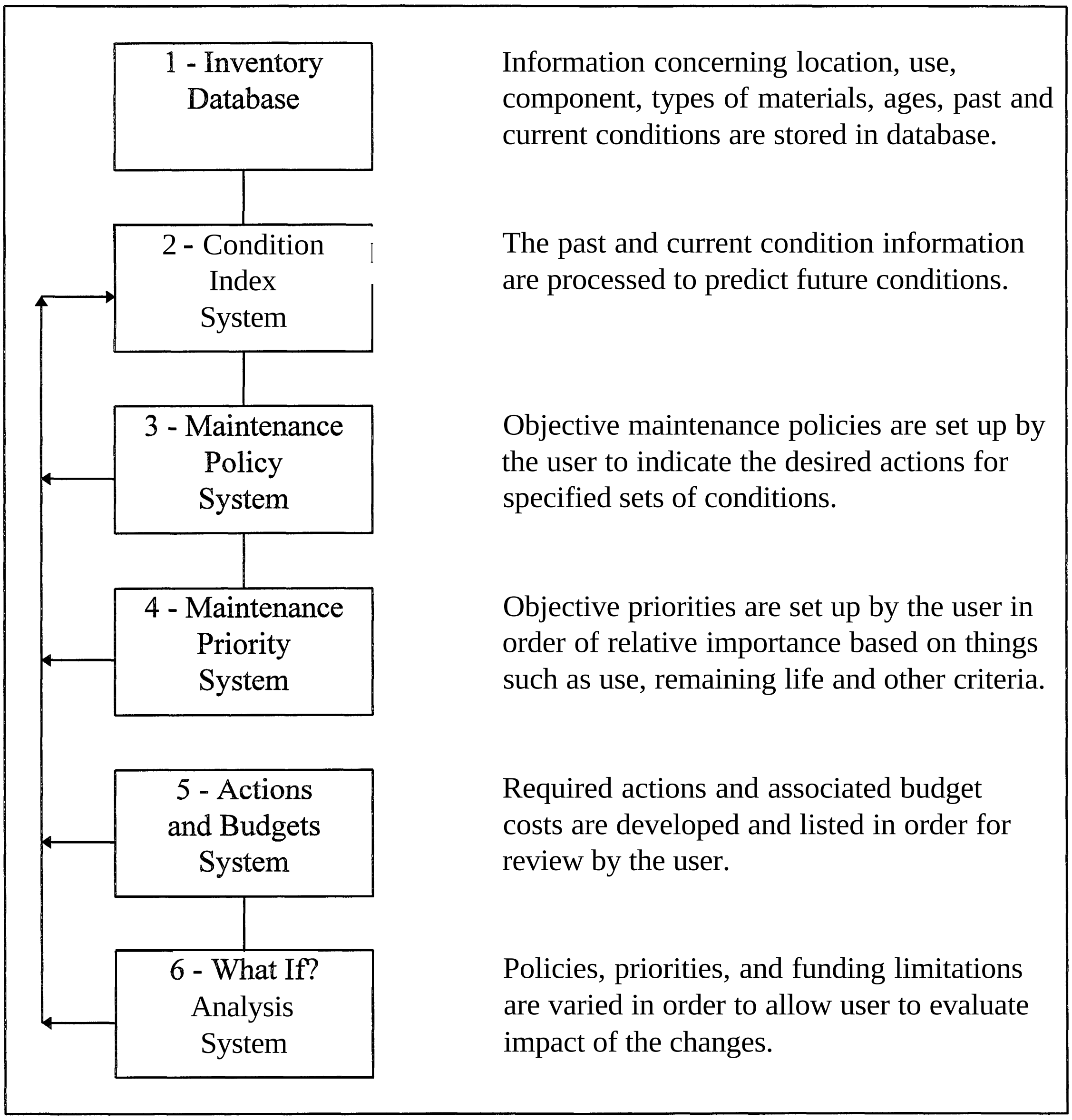

Figure 1. Schematic of conceptual maintenance management system.

The fifth module is the Actions and Budgets System. This module specifies actions and associated costs based on the Maintenance Policy System and the Maintenance Priority System. The sixth module is the What If Analysis System module that allows the owner to evaluate various options. With this tool the owner can change maintenance policies and maintenance priorities and see what impact these changes have on funding requirements. The owner can also evaluate the effect of funding limitations on the overall condition of the entire population or portions of the entire population of facilities. The amount of deferred maintenance can also be assessed in order to help substantiate maintenance budget requests. The project for TXDOT concentrated on modules 1, 2, and 5. This formed the basis for the development of an overall facilities maintenance management system at a future date.

3. TXDOT system

The various systems at each site or facility were divided into Site Related Systems and Building Related Systems. The site related systems included civil/site development and pavements. The building related systems were structure and foundations, exterior walls and windows, roofs, interiors (architecture), mechanical, electrical, plumbing, elevators, and safety.

The condition assessment process began with the definition of data to be obtained and documented during the site and building surveys. Specific information collected included existing construction information and defects for each system. The existing construction information included general system description, use, location, types of materials, components within the system, estimated quantities, and age, if identifiable. System defects for each system were identified and quantified. The information on defects was used to develop immediate repair work items and estimate remaining service lives for each site or building system or major components of each system.

Expected service lives for various site and building systems were established based on published information and the consultant’s experience with previous property condition surveys for several thousand buildings and facilities. Written descriptions of the types and level (severity) of defects typically found within each site or building system as the system ages through its normal service life were developed. These levels of defects were equated to a numerical Condition Index which varied from 10 for a new system with no defects to 0 for a system with defects so severe that the system no longer served its intended function Service life “Aging Curves” were developed to predict the effective remaining service life of a site or building system based on its Condition Index. Figure 2 presents a schematic of typical Aging Curves.

The type, extent, and severity of defects within a TXDOT site or building system allowed determination of a Condition Index for that particular system. The Condition Indices were then used to estimate the remaining service life. Repair costs were prepared from documented deficiencies and replacement times were established based on the effective remaining service life estimates.

4. TXDOT survey procedures

A pilot survey for site and building systems for approximately 100 buildings at IO sites was performed by several teams of trained professionals in December 1994 to test the basic concepts and evaluate reproducibility of the data and results.

Adjustments to the procedures were'made based on the information collected during the pilot survey. The remainder of the sites and buildings were surveyed during April to August 1995.

Each site and building system was divided into "Homogeneous Areas". An area was considered homogenous if it had similar components, materials, ages, and levels of defects. If a site had 500 linear feet of concrete sidewalk where 100 linear feet was new and 400 linear feet was 20 years old, two homogeneous areas were identified, surveyed, and assessed separately. If a building had two different mechanical systems which served different building areas, two homogeneous areas of mechanical systems were identified, surveyed, and assessed. This allowed different Condition Index values to be assigned to each area along with the associated different estimated effective remaining lives. The condition information collected for each building and site were input to a computer database. The number of pieces of data in the database is estimated to exceed 1.5 million.

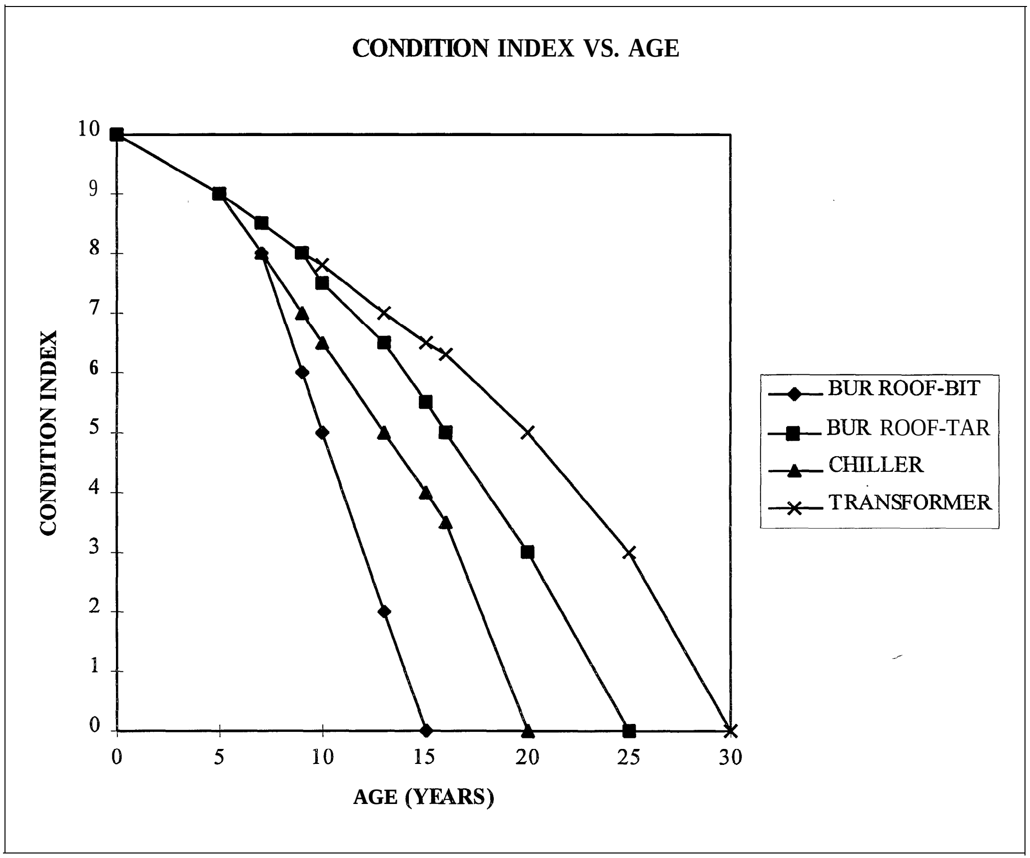

Figure 2. Schematic of Typical Aging Curves.

5. Building condition assessment score

The type of buildings for TXDOT were divided into 3 classes based on the type of occupancy, use, and presence or absence of various systems. The three classes were defined as follows:

Class A — The primary purpose of the building is to create a suitable environment for people to work. This type of building has mechanical, electrical, and plumbing systems, and interior finishes. Examples of Class A buildings include offices and laboratories.

Class B — The primary purpose of the building is to protect the building contents from the outside environment. The building is often enclosed on all sides and has an electrical system, but may not have mechanical or plumbing systems. Examples of Class B buildings include maintenance shops, warehouses, and large pole barns.

Class C — These buildings are termed ancillary buildings. The building may have been constructed by site personnel using available materials. The building may be a prefabricated temporary building or mobile unit without permanent foundations. The building may have minimal utility systems. Examples of Class C buildings include field offices/labs, metal sided storage sheds, and canopies.

A procedure was developed to assign a numerical rating of 0 to 100 for each building surveyed. The number 100 represented a new building with no defects while the number 0 represented an old building with no value. Based on a review of published information and estimated relative values of each system, possible "condition points" were assigned to each system for each class of building as presented in Table 1. Class C buildings were evaluated as a composite entity rather than a sunnnation of individual system conditions.

	Possible Condition Points		
System	Class A	Class B	Class C
Structure and foundations	27	49	Building = 100
Exterior walls	11	20	
Roofs	7	13	
Interiors (architecture)	15	0	
Mechanical	20	0	
Electrical	10	18	
Plumbing	5	0	
Elevators	2	0	
Safety	3	0	
Total points	100	100	100

Table 1. Possible total point distribution for various building systems.

The system condition index values assigned to each system during the field survey were used to develop the Building Condition Assessment Score. The condition points for each system were calculated based on the possible points times the system score or Condition Index as a decimal fraction of the maximum of 10. Thus, if the Condition Index for the roof of a Class A building was 8, the roof portion of the Building Condition Assessment Score was 5.6 (i.e. 0.8 x 7 = 5.6). If the building contained more than one roof, a weighted average based on square footage of each area and its associated Condition Index was calculated. The Building Condition Assessment Score was the summation of the condition points for each building system. The Building Condition Assessment Scores are generally comparable for buildings of the same class. A direct comparison of scores for different classes of buildings is less valid.

The statewide condition point averages for the building systems for the different classes of buildings along with the building condition assessment scores are presented in Table 2. The data indicate that the average system in the buildings has approximately 50 percent of its life still remaining.

	Condition Points					
Svstem	Class A		Class B		Class C	
	max	avg	max	avg	max	avg
Structure and foundations	27	18.5	49	33.3	100	61.2
Exterior walls	11	7.0	20	12.4		
Roofs	7	4.4	13	77 .		
Interiors (architecture)	15	8.8	0			
Mechanical	20	13.1	0			
Electrical	10	6.6	18	11.9		
Plumbing	5	3.3	0			
Elevators	2	1.8.	0			
Safety	3	2.1	0			
Total points	100	65.9	100	65.3	100	61.2

Table 2. Statewide averages for building systems and building condition assessment scores.

The repair and replacement costs were developed utilizing industry pricing methodologies and published information from R.S. Means. A detailed repair or replacement cost estimate was generated for all documented deficiencies. Unit costs for repair and replacement items considered demolition or removal, scaffolding, surface preparation, installation, and clean-up or repair of surrounding areas. Replacement costs also included the cost of associated items or systems affected by the specific item to be replaced. R.S. Means prices were United States average prices adjusted for major city corrections. The repair and replacement costs assumed institutional or government building quality of work. The costs did not include economy of scale effects such as letting a contract for roofing work on a large number of buildings in one contract. The total cost of immediate repairs and replacements was estimated at $62.3 million (US). A total additional cost of $1.391 billion (US) was estimated for the following 28 years.

Quality control measures utilized on the project included using specific survey forms and data documentation formats. Field survey personnel were trained in the use of these forms before they were allowed to go to the field. This consisted of a two day classroom training seminar so that they understood the data collection and condition ratings methods. They each spent a day in the field using the actual forms at the TXDOT District 14 Headquarters in Austin, Texas.

Information returned from the survey personnel during the execution of production inspections in the field was monitored to detect problems so they could be corrected in a timely manner. Senior personnel from the consultant also resurveyed a portion of the field work performed by each survey team to confirm that the data were accurate and consistent.

Summary

The TXDOT building condition survey program was very successful. It allowed the TXDOT to determine the level of compliance with the rule on office space limitations and the cost associated with bringing facilities in compliance. It also allowed TXDOT to estimate and plan for costs for the next three decades. All data was placed in a computer database that will provide the basis for an overall facilities maintenance management system which will allow the TXDOT to manage its facilities in a more economical and sustainable manner. The database was delivered to TXDOT and placed on the local area network at the Headquarters facility.

References

1. Texas Civil Statutes, Article 601b, Section 6.021, Texas Legislature.
2. General Services Commission 115.50 Rule, 73^{rd} Texas Legislature.

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The Product's Milieu -
Towards an effective information domain to deliver sustainable building

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Abstract
Designing to deliver an effective modus vivendi to secure a whole life provision for sustainable building may best be viewed through time sensitive product information demands. But research indicates that emphasis on the project is often at the expense of the finished product, with little practising of environmentally responsible ideals; at best there are a series of short lived links passing through a temporary circuit. Despite the large amount of information relating to sustainable issues, the problem appears to be one of relevance and encoding of disparate information, leading to an unwillingness (or inability) to access relevant information at the appropriate time. There is a need for an effective total information life system to underpin sustainable construction practice beyond the twenty first century.

This paper explores the need for a whole life approach to information to secure a sustainable, life designed, building. Such an approach may require a structural re-alignment for all those parties that build, supply, design, manage and work with buildings, including those who demolish and recover material for reuse and recycling through to reinstatement of a site. An information provision developed through service life planning and life managed buildings, centred upon the effective use of the supply chains of the materials used, within an embodied energy and carbon dioxide life tracking measurement. The sustainable dilemma is that key knowledge is missing from much of the whole life domain, an area in which developments in information technology and expert knowledge systems may go some way to resolving.

A change in the current design models, together with efforts to convince promoters, owners, maintainers and users that information for life should be their goal for sustainability, should now move centre stage. Expert knowledge systems and their electronic idiosyncrasies need careful consideration if, in a resource base sense, life information is to become a sustainable practice.

Keywords: Asset management; Disassembly; Information domain; Expert knowledge systems; Service life planning; Supply chain; Sustainability.

Introduction

The built environment makes an enormous impact on the planet's renewable and non-renewable resource base, contributing to CO2 emissions and other causes of global warming. In all respects, however, it is likely that the rules by which value and costs are shared, by including the externalities created by unsustainable development, will be changed. For example, the conflict between cost and value, combined with the likely phasing in of a built environment carbon tax.

That a more environmentally responsible approach is required is no longer doubted, but perhaps the means and the time frame to act are. Indeed, for some, the issues that need to be addressed are not seen as engineering or technical issues, but softer (and more challenging) factors, encompassing the management, organisation, evaluation and filtering of information. Soft factors require a full understanding of both communication channels and the information needs of a wide variety of potential users, combined with redefined terms of reference for those involved in the supply and value chains of a product, and its associated projects over its service life. Such an understanding may well be beyond the understanding of procurer, user and project participants because of the fragmented nature of the industry and the lack of consistency in the products use and function over time.

Research suggests that detailed evaluation of too many buildings' life fitness remain diffused and often poorly quantified: One felt that in pursuing a life cycle assessment approach (in order to verify the quality of a life design) meant that the information domain relied upon the user experience: a varied experience and one difficult to measure against technical or design parameters. A situation that might initially be made worse if sustainable building focused upon a life planning culture.

What then is the nature of the diffused information domain? Figure 1 illustrates an information system of interrelated components that collect (and retrieve), process, store and distribute information with the aim of supporting decision making, co-ordination and control in an organisation. But, is there such a centre? Is it possible to capture any meaningful life cycle assessment appropriate to a new sustainable model?

No attempt is made in Figure 1 to give it any shape because there is none that is universaly recognised beyond a drawing or documentation classification. It is suggested that only a loose grouping exists in the broad areas intimated. In effect, one might argue that there are two information circuits in train: one concerned largely with the project's modus operandi (process based) and the other concerned with the more permanent part of the project, the product (building) information circuit. In the dispersed model illustrated below there are contractual relationships, but with significantly different legal time frames, contractual risks and penalties: the significance and severity of which will depend upon the relational architecture of the procurement route chosen by the procurer and their advisers, in addition to ownership and legal duties of care.

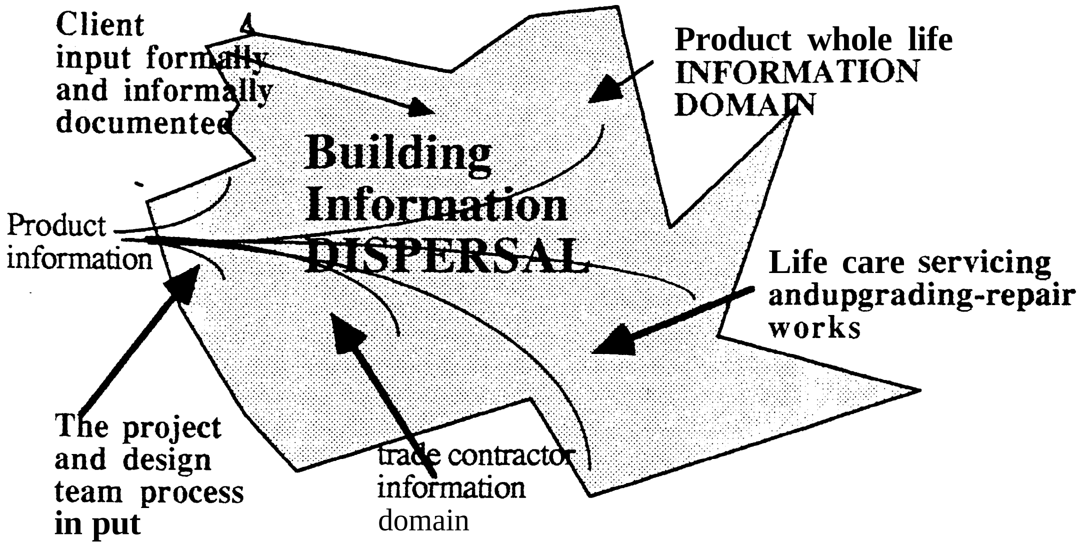

Figure 1
The dispersed information domain - the product's milieu.

Turning to the life care and the challenge facing the facilities manager. The dispersed nature of the building's information needs may in effect lead to a loss of design and technical expertise that created the building, despite everyones best intentions. For example, life cost information is difficult to find and also difficult to collate because of changing measurables, as such the data may have little credibility other than historical interest. It is all to common to find alterations and improvements to buildings carried out without Ml information, thus a Ml understanding of the new relationships that have come about through such action is often lacking. Whilst consultants may well be striving for product improvements and reliability in service life to limit down time, there is little evidence that the issue of information and its use to secure a sustainable future has been researched or responded to on any substantive basis (apart from the odd time capsule of certain project information coming to light through demolition - a theme that is not new). Yet the issue of project process and product information life mix continue to remain dispersed and largely inaccessible. This is an area of growing interest to the facilities management discipline, although to date it has been developing as an end in itself Perhaps the Scandinavian 'total build approach' to facilities management goes some way to addressing the fuller picture in calling for an integrated approach and a lifelong database (1), however there still remains a desperate need for overall vision and its strategic management.

In response to sustainable practise, buildings may have to be designed upon the basis of a life understanding and practice of durability, combined with the sustainable use of materials (2). The concept of designing for disassembly, whether in whole or in part, demands careful consideration, not just of the technical issues, but also of what and how relevant information it attached to the product - which raises the question, can the information be as durable as the product?

The new sustainable product domain

The product domain is made up of a range of products that have varying environmental implications, both in terms of abstraction and processing, and their disposal. Yet it is their green or environmental credentials that have to be questioned if the following product data is not forthcoming;

1. embodied energy rating, including the respective inbound CO2 associated with transportation being identified separately,
2. service life and weighting, or guidance on life reduction factors, to contribute to both service life planning and ultimately any future life gain,
3. environmental impact statements in terms of IS0 14000 I and guidance on recovery and final disposal,
4. life care guidance and options for reducing service loss for future re-use.

Some product manufacturers have started to promote products with (what might pass as) environmentally responsible labelling, but the response is patchy and the information provided is inconsistent and poorly quantified, thus it is impossible for the specifier to make realistic comparisons between competing products. In some respects, products have simply been marketed in a different way (the manufacturing processes tend to stay the same) and the opportunity for innovation spurned. In short, life data is neither readily discernible nor does life testing encourage sustainable development. Put simply, the product domain has yet to match the work of processed engineering capacity. In part this is due to fears over liability on behalf of the specifier and the specifier's office (3) and, because of the way in which the investment market works, it is not always in the procurer's best interest to bring sustainable issues to the fore.

Information lives

Both process and product information is dispersed throughout a building's life, from pre-conception through to its final removal (4). During any project there is usually a significant information base generated which becomes dispersed amongst diverse trade contractors (5). In fact one may introduce the construct of an information life, like the products themselves having lives. There have been calls for a product information system (6) that may help to address the European Directive on Building Products. Fair enough, but how does the designer validate or verify design decisions when the information domain does not embrace a core whole life quantification based upon user experience? When appraising the quality area what information should be retained from the commissioning corrective work area?, or the product's domain (7)?

Information in use

In a richer picture, each grouping may need key information which could contribute to a future whole life design or life track. A track intimated in Figure 2 merges the product and the process information domain to one for, and in, use. In particular, for that anticipated future such life track would be focused upon the practice in the centre.

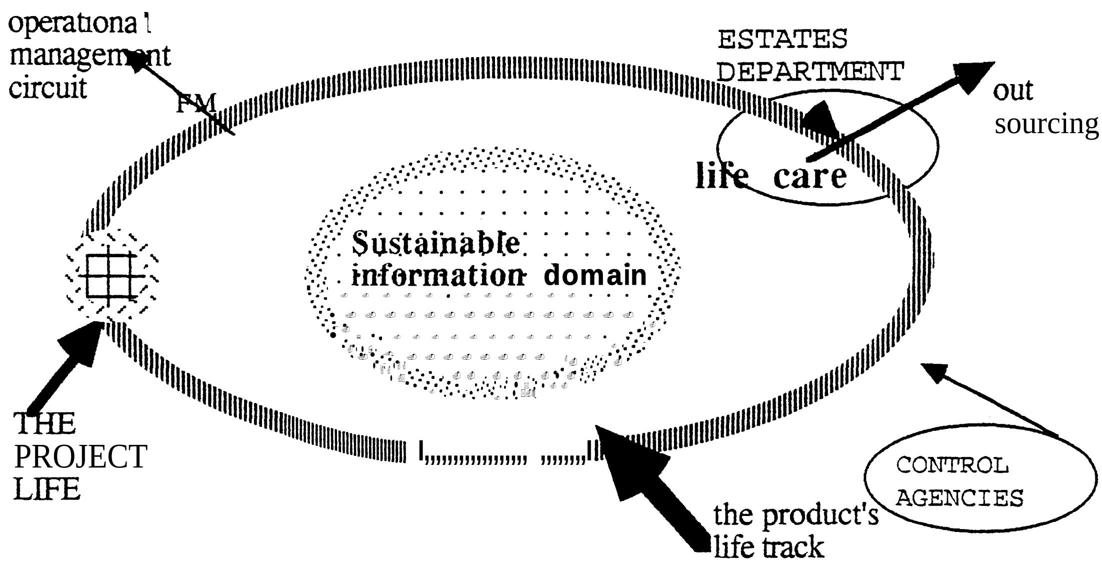

Figure 2
The product life information life track

Despite the extensive range of products, all with different cost in use profiles, the designer seldom has the quantified data required to make an informed decision. It is largely left to the clients estates team, facilities or asset managers to provide or establish reliable cost data. Until such a point is reached the dislocated and diffuse nature of information will act as a barrier to achieving a sustainable whole life briefing. Such information is dependent upon a feedback culture (largely lacking at present) based on accessible serviceability records, which themselves may be inappropriate in a future situation.

Contributors to the information domain may range from the statute makers, with legislation constantly changing both nationally and internationally, through changing users, to some future participants of alteration, upgrading, technical appraisal and/or forensic investigation work. Whatever the input, however, the product may not be proven, worse still the behaviour of a building's constituent parts may be remarkably diffused. Yet for product reliability, the need for verification over time in use requires feedback to secure environmentally responsible design. As such there appears to be an information network problem - we need the medical life records of a building- and its pathological field to become significant if building life quality and resource base management is to become more effective.

There is a common link; the supply chain that is drawn upon, held within the building and ultimately dispersed for reuse, recycling or landfill. To tie a sustainable approach to the supply chain would mean that the title of this paper could be met - provided that all relevant information can be framed in a life information mapping system; an expert knowledge system associated with individual buildings to an electronically standard (GIS?) national sustainable city system.

Design, product life and expert knowledge systems

The established procurement model may now have to include sustainable life quality by addressing the information needs and form of each element, component or system needs; ranging from embodied accounting, cleaning, servicing, repair, replacement and extending to deal with the failure of building services systems. Design has a pivotal role in service life planning (8), but there must also be a willingness from the client to extend their brief to include a use beyond their original intentions and consider disassembly and recycling potential. A wider brief may need the development of a suitable (and user friendly) expert system to allow for life tracking and inventory analysis, thus facilitating the management of the asset over time. Such systems may appear in the future to address service life **(9)** and service life planning (IS0 15686) to permit life auditing during the following stages;

1. pre-briefing,
2. in project process,
3. commissioning,
4. operational status,
5. decommissioning,
6. recommissioning,
7. removal.

Meanwhile, the life methodology needs to be honed so that it is appropriate to the level of assessment called for within its design life performance operating standards. Even so, it is likely that the life information of fitness is likely to remain diffused or unknown and may actually work against the securing of sustainable building due to unexpected maintenance or repair bills until life information is managed.

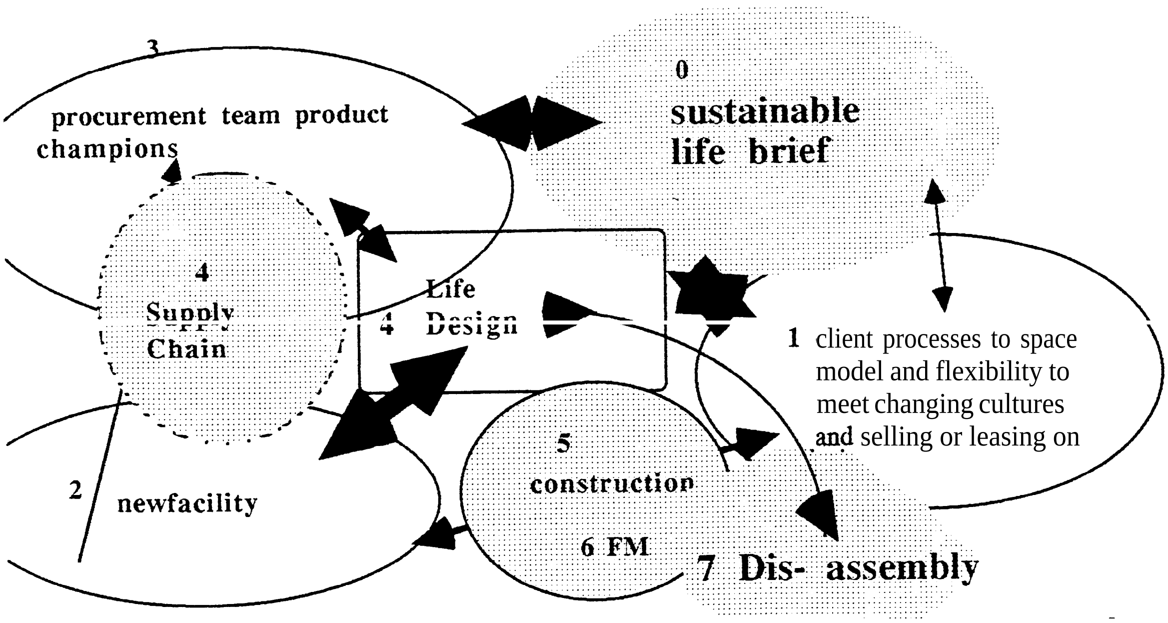

Figure 3
Addressing the discrete life information sub-domains

How can we define what information is needed?, for what stages in the life process?, and in what format? Perhaps a framework akin to the RIBA Plan of Work is needed, a framework extended to include a variety of potential scenarios within the sustainable agenda. Perhaps the model illustrated in Figure 3 might intimate something of what might happen, and why information should be viewed as one of the critical factors in securing future building design and life management of societies' built assets. Currently, the process may terminate at specific stages, but filter out both hard and soft information. But as the building becomes operational the information needs change to that of either monitoring the building or operating life procedures, (eg. inspection or cleaning according to the status set down by supplier, designer or client). Thus at each new briefing there remains an information domain which must be re-interpreted and the whole process reiterated. This could be seen as one of the structural weaknesses of the fragmented design processes which lacks a design information management system or life expert knowledge system.

Whatever future strategies are evolved to secure sustainable building, they must embrace all relevant parties in both the project and product domain. In such an embrace, it should be clear that the manufacturers, material suppliers and the disassembly management sector must be included. As a consequence, in this 'whole life appraisal' the respective parties' trading economics must be balanced within the defined delimiters of a particular development's environmental impact. So whilst one may need to understand the network problem, one must recognise that the role of the architect has changed. Whether an information manager will emerge to take control of the system remains to be seen. Meanwhile, adoption will onlv come about if architects, developers and clients have the desire to pursue common knvironmentally responsible ideals. Similarly, the pressures put upon them by the general public and building users, who will be affected by development, will influence the rate of change for those that do not lead, but choose to follow (10).

From the 'chunky' parts of Figure 3 then, in a future information domain a re-interrogation of the whole design process may be needed or reiterated in any future change of use or enhancement. In responding this may mean the building's service life profile becomes part of the condition based information life system. Next, life information management scope would have to be kept under regular review and updated as change occurs (including sustainable construction initiatives, client and user experience) in part leading to the evolution of more effective life cycle assessment studies, improved supply chain management and environmental initiatives. Finally, beyond the building's operational or decommissioning stage, both the form the information is in and the quality of any record found may have serious implications for those attempting to influence decisions decades ahead or even several centuries down a sustainable life track, through the supply chain inventory.

Conclusion

At present, neither the construction industry nor its many participants are geared up to hold and maintain life documentation. A life documentation that may range from a short term building facility (say 10-20 years) to building stock that might well be standing in 200 years time. A time scale which may be extended if CO_2 becomes a serious delimit on the way one designs and builds. Equally, it is clear that environmentally responsible ideals and practices form a challenge to the majority of participants, who may well continue to act in a familiar manner despite the fact that their knowledge domain has shifted towards sustainable issues. A significant change in attitude, information dissemination and capture is required if sustainable building is to come about - the information is already available, the challenge is to both find it and then use it effectively throughout a buildings service life.

The product team are, in effect, addressing a building made up of many materials, sub-systems, jointing systems and their associated protective coatings and finishes. The information domain may not be able to manage the range of sub-product changes over time, nor would a single firm necessarily have the appropriate data base. It should also be remembered that the technology used in today's data bases and expert knowledge systems may become inaccessible as technology advances (or systems cease to trade) and firms strive to stay up to date. The prospect of information loss is real.

A change in the current design models, together with efforts to convince promoters, owners, maintainers and users that information for life should be their goal for sustainability, should now move centre stage. Expert knowledge systems and their electronic idiosyncrasies need careful consideration if in a resource base sense, life information is to become a sustainable practice.

References

1. Haugen, T. (1994) 'Total Build - An Integrated Approach to Facilities Management (FM in Scandinavia)', in *International Journal of Architectural Management, Practice and Research, 8* pp. 90- 103.
2. Sjostrom, CH (1996) *Durability and Sustainable use of Building Materials,* BRE Seminar Paper, UK.
3. Emmitt, S (1998) 'Fragile Networks and Robust Gates - A View on Managing for Sustainability, *Construction and the Environment, CIB,* Gavle, Sweden.
4. Wyatt, DP & Emmitt, S (1997) 'The Product's Information Network Impediment' in *International journal of Architectural Management, Practice and Research,* 13
5. Nicholson, P & White (1998) *AJ Focus,* January p.48
6. Lutzkendorf (1996) 'A Product Information System is Necessary' in *Building and the Environment in Central and Eastern Europe,* CIB TG8/Building Research Institute, Warsaw, pp25-28.
7. Wyatt, DP & Emmitt, S (1996) 'The Product Quality Chain - Myth or Reality? in *International Journal of Architectural Management, Practice and Research,* **11** pp. 14-22.
8 Bourke, K & Davies, H (1997) *Factors Affecting Service Life Predictions of Buildings,* BRE, UK.
9. Wyatt, DP (1994) 'Service Life Profiling for Sustainable Design' in *International Journal of Architectural Management, Practice and Research, 8* pp.68-76.
10. Emmitt, S (1997) 'The Diffusion of Environmentally Responsible Ideas and Practices' in M. Gray (ed) *Evolving Environmental Ideals: Changing Ways of Life, Values and Design Practices,* KTH, Stockholm pp. 4 l-49.

Recycling Excavated Soil to Back-Filling Material with Liquefied Stabilized Soil Method

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Abstract
Some attempt on recycling excavated soil at site was conducted in order to reduce total amount of soil carrying out of a site. It becomes more and more difficult to find reclamation sites for excavated soil to dump around large cities, typically Tokyo and Osaka in Japan. This trend is due mainly on shortage in reclamation sites around large cities and increase in excavated soil around there.
Under such a circumstance, the ministry of construction in Japan has set a campaign, called Recycle Plan 21 Century, in 1995 and promotes R & D on new recycling technologies in order to utilize more amounts of construction wastes. This paper relates to this campaign and copes with recycling excavated soil.

The developed recycling technique, called "Liquefied Stabilized Soil" is a method that excavated soil is thoroughly mixed with muddy water (or water) and cementing material and then placed in space where back filling is necessary at site. The method is simple to apply at site except a mixing design specification and a mixing machine. Excavated soil may be any kinds, including cohesive soil with high water contents that has conventionally been concidered unsuitable for earth works. Thus, it is thought acceptable widely over construction sites and promotive on recycling.

On the one hand, the method is possible to simplify construction sequence; one of examples is that LSS flows like concrete mortal and its placing requires no compaction effort. On the other hand, the soil after hardening shows good outcomes; at the level of strength where hand shovel excavation is available, the soil is substantially little in shrinkage, permeability, and corrosion under ground water level.

This paper presents a recent application example of this method; a large amount of excavated soil is recycled at site where excavation is done. The application is oriented to reduce soil to be carried out of the site.
The paper also presents a proportional mixing design of LSS and its producing system with outcome of quality control tests.

Keywords
Recycling Excavated Soil, Clay with High Water Contents, Liquefied Stabilized Soil, Back-Filling., Narrow Space, No Compaction

1 Introduction

Some recycling technique for excavated soil to be a back fill material has been developed, namely 'Liquefied Stabilized Soil Method". The method consists of simple stabilizing processes except a mixing specification. It deals with any kinds of soils, including a cohesive soil with high water contents that has conventionally been considered unsuitable for earth works. Thus, the method is thought acceptable widely over construction sites and promotive on recycling.
A common recycling procedure is that excavated soil is carried to a remote plant for stabilizing and carried back to a site for back filling. When an amount of handling soil is large, thousands of trucks necessarily transport them Thus, a plant at a construction site is preferable from environmental and economical points of view. The paper presents a case history of this site plant application with introduction of Liquefied Stabilized Soil Method.

2 Excavated soil

In 1997, excavated soils resulted in 44 million cubic meters in Japan. This amount is 18 % increase from 1992. Except soil with high water contents, excavated soil is basically re-useable without any stabilizing process for an embankment fill material and/or a back filling material. Yet, in past only 15% of them are re-used at construction site while 85% is simply dumped at inland and/or offshore reclamation sites.

On the other hand, construction sites prefer purchasing new sand as a filling material. In 1997, sands used at construction sites are 20.6 millions cubic meters. Among them., a new sand is 68%, a recycled sand 29%, a stabilized soil 3%; these values were 64%, 34%, and 2% in 1992 respectively.
It would be concluded from these data that recycling is slowly progressing but a large amount of reusable excavated soil is still dumped at reclamation sites while a large amount of a new sand is excavated from a natural ground [1].

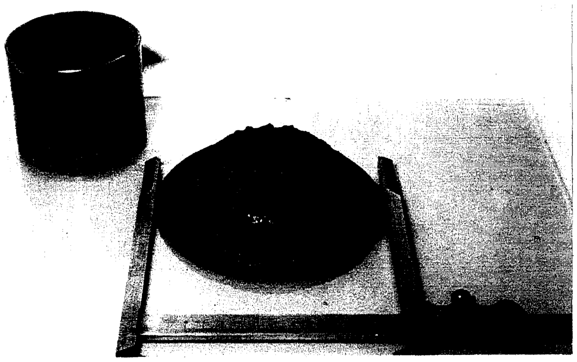
3 Liquefied stabilized soil

Liquefied Stabilized Soil (hereinafter called "LSS"), a new soil stabilization technique is made by mixing soils as principal materials with muddy water (or water) and cement [2]. LSS flows like concrete before hardening. It yields the necessary strength according to proportion of the mixture. It requires no compaction at the time of use and little volumetric shrinkage after hardening. Therefore, it is expected that this stabilized soil is highly applicable for back filling and filling at construction sites where compaction is difficult (Picture 1).

Picture 1 Back Filling of LSS

By adjusting the content of the principal materials, muddy water and a cementing material, it is possible to set the condition of LSS where wanted filling characteristics can be obtained. The filling characteristics are expressed in parameters such as strength, flow value, density, and bleeding ratio. They are decided according to the purpose of the site and produced through a proper mixing proportion after a certain combination of soil tests [3] . The strength of LSS is set at the level fitted for the purpose ranging from the strength of such degree so as to permit hand excavation to the strength equal to the lean mixture concrete.

The fluidity is evaluated by flow value; the spread diameter of LSS originally set in and released vertically from a cylinder measuring 8 cm high and 8cm in diameter (Picture 2). By changing mix proportion., it is possible to yield the required flow value. The flow value changes along with density and time passage. It is known that a low value of 11 cm is the limit to pump LSS out and 14 to 25 cm is a good range [4]. The density is related to all parameters and usually set at 1.4 or higher. The bleeding ratio is restricted to within 1% in most cases or 0.5 % in the case of strictly limited volumetric change like when filling a cavity [5] .



Picture 2 mow value 160 mm of LSS

Beside from above expertise, past series of experiments show that hardened LSS in ground revealed following characters.

1) easy to re-excavate
2) little shrinkage in the ground
3) little corrosion by the running water in the ground
4) almost in-permeable
5) liquefaction free in earthquake
6) no pH rise around the ground
7) slurry waste also useful

Picture 3 Back Filling Space

4 Application example

General condition

In the center of Tokyo, two buildings adjacent each other were constructed sequentially. First building was chosen for this application and was 19 stories building with 4 basements; its total floor area 112,700 square meters, height 90 meters, and ground area 7,500 square meters.

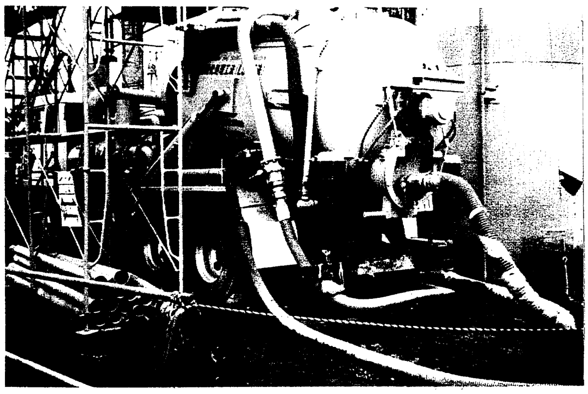
A depth of excavation was 33.5 meters at the deepest and an amount of excavated soil was nearly 261,000 cubic meters. Back filling between a retaining wall and basement structures, typically 4 meters wide, was initially planed by placing sand with compaction. Its space is about 36,000 cubic meters (Picture 3).
A retaining wall was made by a Soil Mixing Wall Method and bottom grounds were improved by deep soil stabilization before excavation so that excavated space was isolated from underground water.

LSS method became attractive comparing to back filling sand and compaction by following reasons.

1) An amount of excavated soil is massive and recycling is preferred.
2) A back filling period overlaps with an above structure work which prefers no men working below.
3) There are narrow spaces where back filling with sand and compaction is barely possible.
4) Excavated soil is a kind of clay with high water contents.

Application of LSS

It is common that LSS plant is set remote from a construction site. Its procedure is that first excavated soil is carried to the remote plant, secondly it is processed to LSS, and LSS sends back to a site for back filling. This system is available in adjusting time lag of excavation and back filling and/or supplying LSS to any sits when it is necessary.



Picture 4 Outlook of a Movable Plant

However, the systemneeds transportation carrying soils out and bringing LSS back, resulting not ignoring amount of cost.

This application uses a site plant experimentally. Since two buildings are constructed in some time differences, it is thought possible that excavated soil at one building is used for the other. For this application, a movable mixing plant was developed to reduce a plant area (Picture 4 and Figure 1). This plant is moved out of site easily when no needs. In addition, construction sequence is carefully re-scheduled so that amount of soil to excavate and LSS to back fill is balancing.

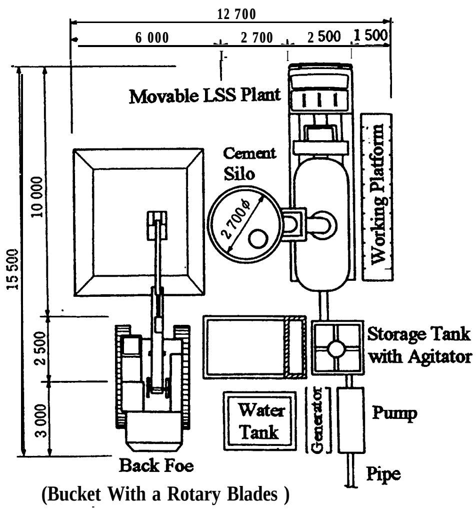


Figure 1 Occupancy of A Plant

Soil Property and Mix Proportion

Excavated soil is mainly Kanto-Loam whose characteristics are seen in Table 1. Since silt and clay proportion is 66%, bleeding can be controlled within 1% without any treatment. However, it is difficult to make dense LSS with this material alone.

Main properties wanted for LSS are strength and bleeding ratio. Table 2 shows target properties of LSS for this application.

Unconfined strengths were set at the level equal to that of surrounding grounds. At that levels hand excavation is still available and substructure was sustained firmly by lateral earth pressure. However, target strengths were modified somewhat higher by two considerations. A Soil Mixing Wall exhibits stiff behavior and soil between the wall and substructure is preferred similar to that of the wall. A target density is slightly lower than 1.4 and higher strength can be secure in durability.

A bleeding ratio is less than 1 % and expected no segregation with water and no substantial shrinkage in the ground.

A density prefers being high because of durability. To do so is to reduce a void in LSS; concretely lowering water contents. On the other hand, it becomes difficult to flow when water contents becomes low; placing prefers a high flow value. At a flow value of 300 mm, LSS flows by less than 1% gradient. In this proportion, a designed flow value is set low for gaining more density.

Table 3 is a designed mix proportion for the target properties. Since an original soil is rather uniform, one proportion is adopted.

Table 1 Excavated Soil Characteristics

Soil	Gravel	Sand	Silt	Clay	Water Contents	Unit Weight
Kant0 Loam	11.7%	22.2%	24.0 %	42.1 %	80.0 %	1.42 (t/m^3)

Table 2 Target Properties for LSS

Location	Initial UCS (kgf/cm^2)	Final UCS (kgf/cm^2)	Bleeding Ratio(%)	F. Value (mm)	LSS Unit Weight (t/m^3)
Above GL – 10 m	2.00	10.2	Less 1%	Over 160 mm	1.387
Below GL -10 m	3.75	10.2	Less 1%	Over 160 mm	1.387
Concave Space of Substructure	10.2	10.2	Less 1%	Over 160 mm	1.387

Note: UCS at 28 days and $1\,kg\,f/cm^2 = 100\,kN/m^2$

Table 3 Mixing Proportion

Excavated Soil	Water	Cement
664 kg	505 kg	218

Cement is for 1.25 time of target strength

LSS work at site

Figure 2 shows a system flow at this site. Excavated soil is moved to the plant in a site. Sequentially, it is mixed with water by a bucket rotary mixer. Density of slurry is monitored every minute so that it meets with the mix design. A movable plant draws in necessary amounts of slurry and cementing agent by a vacuum and a measure. After cementing agents are uniformly mixed among slurry, LSS has been made and sent to a storage in which an agitator runs preventing segregation. Finally, LSS goes to where back filling is necessary by a squeeze pump.

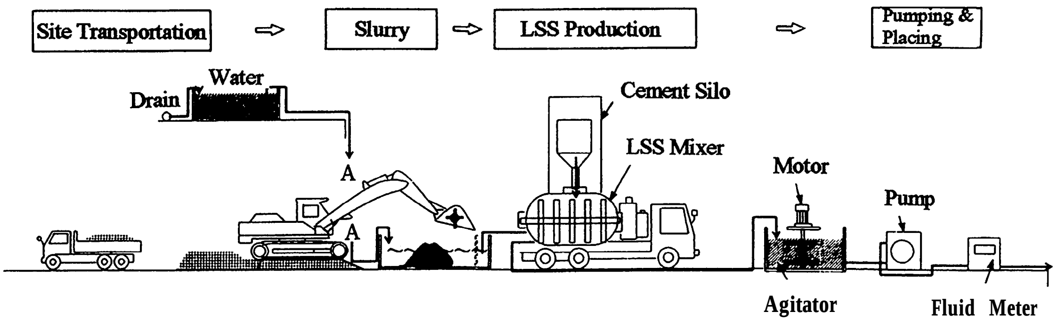
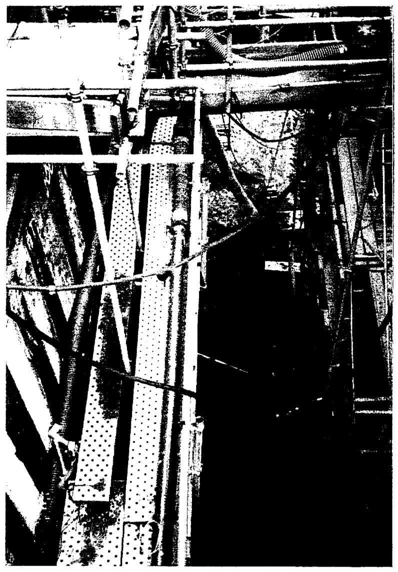


Figure 2 Site LSS System Flow

Pumping does placement of LSS. Pipes for placement are set when no structural works are active. They are easy to carry and joint together. Length of piles is long, say 250 meters at longest, their setting is arranged in a way that their length is shorter and bends are less. Picture 5 shows LSS placing. A previously set pipe discharges LSS where back filling is necessary. Note there is few men in back filling operation.

This placement of LSS consists of three phases. The first phase is for back filling until one third of total depth from the bottom Around the top, there are stress units of anchors and lateral bracing. A total length around the substructure is about 350 meter. A pipe is extended to the far end from the plant site and discharges LSS. During this far end placement, water, if any remained at the bottom, is pushed by LSS toward the location of the plant and drained. After LSS accumulates near the bracing, the pipe is located where LSS piles up low, typically 15 meter away for the previous discharge point. A placement continues till a surface of LSS coming equal to the other. When placed LSS gets hardened at the surface, stress units and lateral bracing are taken apart without scaffolding works. The second and third phases go up to next stress units of anchor and lateral bracing level with same procedure of the first phase. When LSS comes to near ground, its surface is covered by excavated soil. Figure 3 shows results of placement in a day. A total amount of placed LSS became 36,000 cubic meters.



Picture 5 Placing LSS

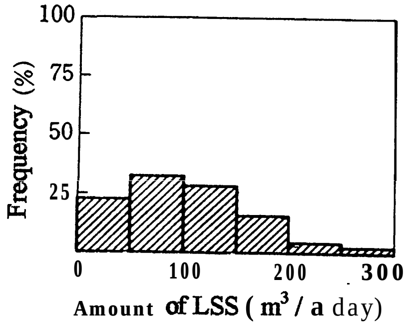


Figure 3 LSS produced in a day

Quality test

Quality control tests are conducted before and after hardening of LSS. The former is for confirming if LSS is adequately produced according to the mix proportion while the latter is for assuring quality of placed LSS. The former type of a quality control test is done every batch in terms of slurry density, LSS density, flow value and the latter type is two sampling a day in terms of bleeding ratio and unconfined strength. Test results are shown in Figure 4 to 6. Produced LSS are fallen over acceptable ranges of the target values and there are no defect products. The figures also indicate no significant deviation in distribution.

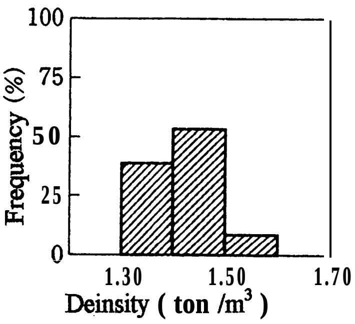


Figure 4 Density Distribution

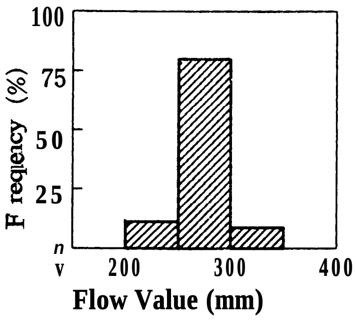


Figure 5 Flow Distribution

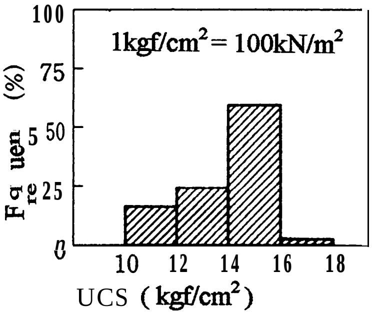


Figure 6 Strength Distribution

5 Summary

A newly developed recycling technique is applied for a soil with high water contents at the construction site, This application indicates following expertise;

1) Excavated soil with high water contents is easily reused at a site and considered as useful resources.
2) A small plant space is capable of producing a large amount of LSS, in this case 300 cubic meters a day at maximum.
3) Quality of LSS is steady if excavated soil is uniform; this implies a site plant is preferable to a remote plant, which collects any kinds of soils.
4) Placing LSS with pumping reduces labor resources significantly.
5) LSS little segregates into water if bleeding ratio less than 1%.

Acknowledgement

The Liquefied Stabilized Soil Method was developed by the collaboration study with Public Work Research Institute, Ministry of Construction and Japan Association of Representative General Contractors during 1992 to 1997. This case history was conducted after this research. During that time, many research engineers contributed significant efforts. Here at the end, authors give special thanks to those related the development, especially, Dr. Miki, H and Mori, N at the Public Work Research Institute.

References

1. A Committee of Promotion and Public Relation on Construction Wastes Recycling, (1996) ***A Proposal on Promotion in Construction Recycling,*** Foundation of New Construction Technology Center, Tokyo
2. G. Kuno *et* al (1997) ***Liquefied Stabilized Soil Method,*** ,Gihodo Publishing Co.,

Tokyo, Japan

3. Kuno G., Miki H., Mori N., and Iwabuchi J., (1995) Study on Back Filling Method With Liquefied Stabilized Soils as to Recycling Excavated Soils. *Individual Papers,* **20th** World Road Congress, Montreal, Canada
4. G. **Kuno,** J. **Miki H.,** Mori N., and Iwabuchi J., (1996) Application of the Liquefied Stabilized Soil Method as a ***Soil*** Recycling System *Proceedings,* the Second **International** Congress on Environmental **Geotechnic,** Osaka, Japan
5. G. **Kuno,** J. Miki H., Mori N., and Iwabuchi J., (1997) Filling a Cavity under Pavement of Urban Road with Liquefied Stabilized Soil. ***Road Construction Rehabilitation and Maintenance,*** XIII Th **IRF** World Meeting, Toronto, Canada

Building Physics - No Way around It

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Abstract
In recent years, growing interest in life cycle cost analysis regarding environmental and economic factors has focused on the choice of materials with regard to the chemical composition, embodied energy, emissions of gasses and other more or less quantifiable processes. In some cases, this concentration on material properties has lead to inferior solutions regarding thermal performance, moisture protection and durability in general. In this paper, an attempt is made to establish a relation between design that neglects common theories of building physics and the consequent environmental and economic cost. The study is based on a Swedish single-family house having a normal design where components are successively exchanged to materials and constructions that are today commonly known as being environmentally feasible.

For each solution, the method estimates the impact on the use of energy and emission of greenhouse gasses. With additional information the need for maintenance, repair and replacement at some intervals should also be included in such a study. The analysis will always be partly built on unreliable input data and subjective reasoning. The aim here is not to give exact results but to place emphasis on the importance of a proper perspective for the technical design when considering the life cycle.

For both analysed cases with the timber-framed wall and the different methods for airtightness it is evident that their role in the operation of the buildings dominates the differences in the environmental impacts of the construction itself. It can be concluded, from these examples that recommendations on environmentally feasible constructions based on unreliable information regarding the environmental impact of materials without considering the functionality of the material and the constructions as a whole over the lifetime of the building or building component, are to be considered as more or less organised desinformation to builders and buyers.

Finding alternative building materials and more effective means for the building process is in no way to be considered as unimportant in our efforts for a better environment. However, the examples above show that the functionality of alternative solutions and materials must be considered when designing from the perspective of the life cycle of a construction before these can be recommended as fulfilling the requirements of both sustainability and functionality.
Keywords: durability, embodied energy, emissions, energy use, performance, service life

1 Introduction

In recent years, growing interest in life cycle cost analysis regarding environmental and economical factors has focused on the choice of materials with regard to the chemical composition, embodied energy, emissions of gasses and other more or less quantifiable processes. In some cases, this emphasis on material properties has lead to inferior solutions regarding thermal performance, moisture protection and durability in general. In this paper, an attempt is made to establish a relation between design that neglects common theories of building physics and the consequent environmental and economic cost. The study is based on a Swedish single-family house having normal design where components are successively exchanged for materials and constructions that are today commonly known as being environmentally feasible.

2 Methodology

When assessing the environmental impact of different building materials, the chemical composition and emissions have to be weighed to a comparative quantity. This is difficult but has been done using different approaches [1]. The next difficulty is to choose between different materials based on an assessment of environmental impact. The difficulty here is that the environmental impact partly refers to the material and partly to the functionality of the material as a part of a complex building structure in the exterior envelope of a whole building. When making a choice between two materials with the same functionality the pure material properties can be considered. When choosing between materials with different functionalities the obvious risk is that the role of the material properties will dominate the functionality aspect and that this will lead to sub-optimisation that will not ultimately benefit the global environment. Also when a material with the same functionality but at a higher price is chosen, this has to be matched against the cost efficiency of other measures that could benefit the environment.

3 Case study of the vapour barrier in a timber-framed wall

3.1 Technical description of the timber-framed wall

The timber-framed wall built in Sweden today normally consist of materials that have been developed to fulfil one or two functions, i.e. separate material layers are used for vapour barriers, efficient insulation, surfaces etc. This permits the wall to meet high demands on performance but also it becomes vulnerable to damages and poor workmanship.

The layers of the timber-framed wall, starting from inside the interior cladding, consists of: gypsum board with paint, vapour barrier made of 0.2 mm polyethylene (PE) film, timber frame and light weight insulation where the timber part is assumed to be 15 %, wind barrier of low density tarred fibre board, a ventilated air gap and exterior cladding consisting of a wood panel.

The timber-framed wall does not have the same built-in natural airtightness as does, for instance, the masonry wall. The combination of studs and porous insulation demands both internal and external supplementary layers to secure the airtightness and to prevent air exchange between the insulation and the outdoor air.

3.2 Cost-benefit analysis for replacing the plastic film

One of the major aims of the enthusiasts for a better environment, has been to remove or replace the plastic film that over the years has traditionally been used as a vapour barrier on the inside of timber-framed constructions. The function of the plastic film is partly to provide a high vapour resistance on the inside of the construction and to provide adequate airtightness. There are two different dominating strategies for replacing the plastic film. The first is to eliminate it and use insulation materials that are supposed to absorb and release moisture over an annual cycle. The second is to replace the film with some other technology, such as an interior surface cladding with surface treatment and carefully made joints to provide good airtightness. A cost-benefit analysis for plastic film and mineral wool batts replaced by cellulose insulation can serve as an example of the actual complexity of such problems:

Eventual cost
- Extra work and materials for interior cladding surface treatments and joints
- Higher material cost for cellulose based insulation materials
- Increased energy use due to reduced airtightness
- Increased wall thickness due to higher thermal conductivity
- Increased energy use due to higher humidity level in the insulation layer
- Increased environmental cost due to reduced service life
- Higher risk for emissions from the interior of the construction to the inside.

Eventual benefits
- Materials from renewable sources
- The environmental cost of the plastic film is saved
- Material and installation cost for the plastic film is saved
- Has a market value since it is easy to convince ignorant buyers about the health hazard connected to the use of plastic film.

Environmental data on construction materials, components and elements can vary within wide limits depending on where the products are produced and applied. We have chosen data provided by other researchers [1, 2] and have studied two alternative constructions, one with plastic film vapour barrier and mineral wool insulation batts (thermal conductivity 0.036 W/mK) and one without a vapour barrier and with cellulose insulation (thermal conductivity 0.039 W/mK). For the construction we summed the energy used and the greenhouse gasses emitted to the atmosphere in relation to the production of materials and construction. We referred to the references for the basic values. To relate these values to possible emissions owing to the energy used during the operation of the building over 70 years we used oil burned in a rather effective plant as a reference. These values represent a possible scenario but are by no means valid in all cases. The choice of oil as a reference source for heating is of course disputable. Together with hydro power and nuclear fission the burning of oil is still a major source of heat in Sweden and one can assume that a great part of a marginal increase in energy consumption will be met with oil burners.

Table 1 shows the total energy used and the most important greenhouse gas emissions for the two construction alternatives.

Table 1. Used energy and air emissions for two wall construction alternatives including effects of energy use for heating during 70 years of operation.

Timber framed walls	**Energy MJ/m²**	**CO_2 g/m²**	**SO_x g/m²**	**NO_x g/m²**
Wood	374	373	2	14
Vapour barrier	14	806	0.2	1.7
Nails and screws	1	**59**	**0**	**0**
Glasfibre wool batts	114	4206	3	18
Paint	0.9	57	0.3	0.1
Gypsum board	75	5043	33	100
Wood fibre board	6	**49.6**	0.1	0.3
Sum for construction	**584.9**	10593.6	38.6	134.1
Operation	6113.9	463437.1	2323.2	917.1
Constr. and operation	6698.8	474030.7	2361.8	**1051.2**
Wood	374	373	2	14
Nails and screws	1	**59**	**0**	0
Cellulose insulation	40.5	**972.2**	7	13.6
Paint	**0.9**	57	0.3	0.1
Gypsum board	75	5043	33	100
Wood fibre board	6	**49.6**	0.1	0.3
Sum for construction	**497.4**	6553.8	42.4	128
Operation	6352	481478.5	2413.7	952.8
Constr. and operation	6849.4	488032.3	2456.1	1080.8
Total difference	**150.6**	**14001.6**	94.3	29.6

Replacing the mineral wool and plastic film with cellulose insulation reduces the embodied energy by 20 %, the CO_2 and NOx emissions by 40% and 5 % respectively, whereas the SOx emissions are increased by 4 %. When the operation of the wall with 130 degree-days per year over a period of 70 years is included, CO_2 emissions increased by 140 %, SOx emissions by over 200% and NOx emissions increased by 20 %.

The above examples shows that choosing a material with lower thermal performance very rarely will be environmentally feasible even though the material itself may have less embedded energy and fewer greenhouse gas emissions. The difficulty with such a comparison is the choice of cases for comparison. Replacing the cellulose fibre insulation with mineral wool with higher thermal conductivity would also have given increased environmental impact. There is also an economic angle. If the two construction alternatives had been given different insulation thickness to reach the same price per m^2 for the construction a more expensive product like the cellulose fibre insulation alternative would have shown much higher environmental impact. The above analysis also assumes the same airtightness for both constructions.

3.3 Life cycle cost assessment of the timber-framed wall

The building design process is a series of choices. In earlier times it was sufficient to make the monetary cost - benefit analysis. That is to regard the economy of the project from a present value perspective for a given specification based on technical and construction related aspects and as well on estethic performance. Now we should also consider the environmental impact of our choices. The economic and environmental impact can also be closely related.

In a timber-framed construction the thickness of the timber frame for structural purposes is approximately 100 mm. To maintain a low U-value the thickness of the frame has to be increased beyond this just for insulation purposes. A wall with 200 mm mineral wool and a crossing-stud timber frame gives a U-value of approximately 0.20 W/m^2K. If the wall is instead insulated with cellulose fibre insulation the U-value can be increased to 0.22 W/m^2K. To compensate for the higher thermal conductivity the thickness has to be increased to 220 mm. The additional cost for the cellulose fibre insulation is about 40 SEK/m^2 for the original thickness and about 25 SEK/m^2 for the extra construction thickness. The additional cost for the same insulation performance is therefore 65 SEK/m^2 or about 10000 SEK for a 150 m^2 house. This amount could instead be invested in an air-to-air heat exchanger or an exhaust air heat pump saving 3000 kWh per year or 2.5 m^3 of oil over a 70 year lifetime. The other choice would be to insulate with the same thickness resulting in an increase in energy use by 400 kWh per year or about 0.4 m^3 of oil which is still large compared to the 30 1 of oil saved by not using the plastic film.

The airtightness of a timber framed construction has normally been provided with a plastic film behind the interior cladding. The oil consumption for heating infiltrated air is for a 150 m^2 house with 0.5 air exchanges per hour approximately 50 m^3 over a lifetime of 70 years. An inferior construction in term of airtightness can easily give an increase in infiltration of 0.05 - 0.1 air exchanges per hour resulting in an extra consumption of 5-10 m^3 of oil over the lifetime of the building which can be compared with the oil saved by not installing a plastic film being less than 100 kg.

Owing to the relatively small impact of the construction compared with the operation, the impact of functionality of the construction dominates the total picture. This also means that the question of service life is suppressed looking at the construction for itself. If however the construction can be seen as the weakest link in the service life estimation for the whole building with its infrastructure and also including the possible negative effects of the decay on the construction on the indoor environment the picture becomes different.

4 Case study of caulking joints between walls and windows/doors

This example is illustrated by a rectangular one story house of 10 by 12 meters. The window area is assumed to be 18 % of the floor area and the joint length is 4 m per window with two doors giving a total crack length of about 100 m. For simplicity we assume 25 m on each face of the building and no other air leakage paths present. The house is equipped with a mechanical exhaust and supply ventilation system that takes care of the desired airchange rate. Additional air leakage is undesired. The house is placed in Stockholm with an average heating season temperature of +2°C and 4 m/s wind speed. Indoor temperature is 20°C.

Results from laboratory measurements of air leakage of different joints between windows/doors and wall frame, and the corresponding air leakage curves were found in literature [3, 4]. The relations between air leakage flow and pressure difference from these measurements were expressed as:
$q = 0.0440 \cdot \Delta p^{0.86}$ m^3/hm for a joint sealed with mineral wool packing but without elastic compound and $q = 0.0012 \cdot \Delta p^{0.79}$ m^3/hm for a joint with elastic compound. For a well performed joint using polyurethane foam sealing the value was practically zero.

To find a relevant seasonal average pressure difference for these air leakage paths, standard pressure coefficients for wind perpendicular to the long face of the building were assumed. Thus, the air infiltrates through the windward wall of the building and exfiltrates through the other walls. The building, including pressure coefficients, wind speed and temperatures were inserted in the IDA-MAE computer program to find the resulting pressure differences and air flows [5].

The calculated reduced air flow from using elastic compound in addition to mineral wool packing amounted to 8.6 m^3/h for this house, which could be estimated to reduce heating need with about 300 kWh/year in the Stockholm climate. Using the polyurethane foam, which normally is installed without mineral wool packing, the reduction will be slightly larger.

In Table 2, the environmental impact of three types of joints is estimated by total energy use and emissions to air. Also the saved emissions originating from energy saving (reduced oil burning) over a 20 year service life owing to the reduced air infiltration is also provided. In this example, a 20 year service life was chosen as reasonable for the three types of joints considering functionality and seasonal moisture and temperature movements. Environmental impact data is taken from previously mentioned sources and [6, 7].

Table 2. Environmental impact for three types of joints for a single-storey house (100 m joint length) compared to the saved emissions over 20 years from reduced energy losses.

	Type of joint	Mass kg/m joint	Total energy use MJ	CO_2 g	SO_x g	NO_x g
1	Polyurethane foam	0.030	313.1	12.19	0.0573	0.0533
2	Butyl (PP base exc. filler)	0.180	1 440.5	19.8	0.198	0.18
	Backing rod (LDPE)	0.010	83.0	0.61	0.0027	0.0079
	Glassfibre wool packing	0.090	186.5	6 882.5	4.91	29.45
	Sum of materials		1 710.0	6 902.9	5.1	29.6
3	Glassfibre wool packing	0.090	186.5	6 882.5	4.91	29.45
	Saved emissions over 20 years (joint 2 compared to joint 3)		21600	1637280	8208	3240

As can be seen from Table 2, the impact of the saved emissions totally dominates over the impact from the materials for all of the investigated parameters. This example shows the importance to create building detail solutions that gives as low energy use as possible.

A new trend that can be seen is to recommend packing with cellulose fibre insulation and omitting the caulking. Measurements are not available but assuming that the cellulose fibre insulation will give similar results as packing with only mineral wool, it is obvious that small environmental benefits looking only at the construction itself will quickly be eaten up during the first years of operation.

5 Conclusions

From the above examples it can be concluded that recommendations on environmentally feasible constructions based on unreliable information concerning the environmental impact of materials, without first considering the functionality of materials and constructions as a whole over the lifetime of the building, must be considered as more or less organised desinformation to builders and buyers. Whether these are commercially or otherwise motivated, these kinds of recommendations could be harmful to the environment because they could lead to wrong decisions and also because they undermine the more serious long-time work for a better environment based on science and technology.

Finding alternative building materials and more effective means for the building process is in no way to be considered as unimportant in our efforts for a better environment. However, the examples above show that the functionality of alternative solutions and materials must be considered when designing from the perspective of the life cycle of a construction before these can be recommended as fulfilling the requirements of both sustainability and functionality.

6 References

1. Nilsson, M., Gullberg, M. (1998) Externalities of Energy. Swedish Implementation of the ExternE Methodology. ISBN: 91 88714 5 1 9. Stockholm Environmental Institute.
2. Erlandsson, M. (1995) Environmental Assessment of Building Components. TRITA-BYMA 1995: 1, KTH, Stockholm .
3. Höglund, I., Jansson, B. (1984) Joint Sealing between Window (Door) Frames and Walls. Conference Proceedings, Windows in Building Design and Maintenance, Gothenburg June 13-15 1984. Swedish Council for Building Research D13: 1984, Stockholm.
4. Levin, P. (1991) Building Technology and Air Flow Control in Housing, Swedish Council for Building Research D 16: 199 1, Stockholm.
5. Sahlin, P., Bring, A. (1995) The IDA Multizone Air Exchange Application, Version 1 .01, May 1995. Bris Data AB and the Department of Building Sciences, Div. of Building Services Engineering, KTH, S- 10044 Stockholm, Sweden.
6. Boustead, I. (1993) Eco-profiles of the European plastics industry. Report 3 Polyethylene and polypropylene. The European Centre for Plastics in the Environment, Brussels.
7. Boustead, I. (1997) Eco-profiles of the European plastics industry. Report 9: Polyurethane precursors (TDI, MDI, Polyols) (second edition). Association of Plastics Manufacturers in Europe, Brussels.

Evaluation of the Factor Method to estimate the service life of building components

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Abstract
In this paper is presented an evaluation of a method to estimate the service life of building materials or components. The method is called the Factor Method, and it is based on a reference service life (RSL) and a set of factors to be multiplied with each other and with the RSL. The Factor Method is proposed in an IS0 Draft Standard which is under development.

Intitally, a brief presentation is given of the background and needs for service life prediction which has appeared during the last 10-l 5 years. International as well as national research and standardization activities are mentioned.

After a presentation of the Factor Method itself, a survey is given of important publications which contains general descriptions or criteria which should be applied to methods for prediction or estimation of service life. Finally, a discussion of the Factor Method is given, including suggestions for further studies to improve the method.

In the conclusions it is stated that the Factor Method has gained specific interest over the last years, but little experience has been gained by use of the method so far. The discussion has shown that there are several aspects of the method which need to be further evaluated, in order to achieve a method which is sufficiently reliable and user-friendly. There is also a great need for input data for various materials and components in order to use the method. More studies are going on in order to develop the Factor Method further, or to get more experience with the method, e.g. within the joint CIB W80/RILEM-SLM group "Service life methodologies".
Keywords: service life, estimation, Factor Method, building materials, building components.

1 Introduction

Over the last decades, there has been an ever increasing focus on the needs to determine durability and service life of materials, components, installations, structures and buildings. This has been based on two important aspects:

- environmental issues: lack of material and energy resources and pollution stress on the environment
- economical issues: the total value of the built environment on a national level and the value of each part of it (buildings, structures, roads, quays, etc.) for the specific owner (authorities, private companies or individuals). The conditions of the built environment and the annual costs of management and maintenance are of major importance for the economy and the competition.

The importance of these aspects has been reflected in several intiatives and activities at both an international as well as a national level. Some of those are briefly mentioned here:

- the UN Conference on Environment and Development (UNCED) which was held in Rio de Janeiro, Brazil, in 1992. This conference resulted in two international agreements, two principal statements and an Agenda for a global sustainable development (Agenda **21)** [1]
- adoption of the Construction Products Directive (CPD)[2] within the European Union (EU) in 1988. In the Directive six essential requirements are given, and a statement that one or more of these requirements have to be fulfilled during the economical working life of the actual material or component
- publication of a RILEM Recommendation for service life prediction [3] in 1989
- publication of a Principal Guide for service life planning of buildings in Japan [4] in 1989 (English edition in 1993)
- international research and development activities within CIB (W60, W70, W80, W94) and RILEM
- international standardization work within IS0 (TC 59, TC 207)
- publication of national standards and building regulations regarding durability and service life of building materials and components. As examples the following countries can be mentioned: Canada, New Zealand, Norway, United Kingdom.

2 The Factor Method

The concept of the factorial evaluation of the service life as described in the Japanese Principal Guide [4] has been introduced in a proposal for an International Standard for service life planning of buildings [5]. The proposed Factor Method is said to *"allow an estimate of the service life to be made for a particular component or assembly in specific conditions"*. The method is based on a reference service life (RSL) and a series of modifying factors that relate to the specific conditions of the case. The RSL is said to be *"in essence the expected service life in the conditions that generally apply to that* *type of component or assembly..... ".* The RSL is similar to the standard service life as defined in the Japanese Principal Guide.

In the present version of the IS0 Factor Method (Draft of May 1996), the following factors are used:

A material and components
B design
C sitework/execution
D indoor environment
F outdoor environment
G operating characteristics
H maintenance level

The Factor Method is then expressed as the following equation where the estimated service life of a component (ESLC) can be calculated by a combination of the reference service life of the component (RSLC) and the factors mentioned:

$$ESLC = RSLC \times \text{factor } A \times \text{factor } B \times \text{factor } C \times \text{factor } D \times \text{factor } F \times \text{factor } G \times \text{factor } H \quad (1)$$

In an informative appendix of the Draft Standard, three worked examples for use of the Factor Method are given. These examples are dealing with prestressed steel lintel, softwood window and fibre-based cement slates.

3 General requirements for service life prediction

Service life prediction of materials, components, building elements or buildings is rather difficult. It can be based on two different principal approaches:

- deterministic approach
- probabilistic approach

In the deterministic approach, exact figures are used and no evaluation of uncertainty or statistical variation of the factors is considered. In the probabilistic approach, considerations are shown to the fact that the reference service life (RSL) as well as the factors vary with a statistical distribution within certain limits.

Since the first half of the 1980s, much work has been done within international research and standardization organizations (CIB, RILEM, ISO) and on a national level in some countries to develop methods, tools and standards for description of service life. In many of these studies, efforts have been put into the description of general requirements which should be posed to service life prediction or estimation methods. Some important examples of such requirements are mentioned below.

As mentioned in clause 2, a RILEM Recommendation based on work within a joint CIB/RILEM Committee was published in 1989 [3]. The document outlines a systematic approach or methodology for service life prediction of building materials and components. The methodology is said to include the identification of needed information, the selection or development of tests, the interpretation of data and the reporting of results. It uses an iterative research approach, thereby permitting improved predictions to be made as the base of knowledge grows. Mathematical analyses needed for prediction of service life are not described in detail, but either deterministic or probabilistic analyses may be used.

The RILEM Recommendation is intended to be generic, and therefore applicable to all types of building materials and components. Specific test methods and test equipment will vary with the materials or components to be evaluated and with the user requirements, and therefore are not included in the document. The Recommendation has been used as a basis for the development of the IS0 Draft Standard [5].

In the Japanese Principal Guide [4] it is mentioned that various principles for the prediction of physical service life has been proposed. Some national development and standards are mentioned (US, France, Australia, Japan), along with the work of joint CIB/RILEM Committees. It is stated that the system for service life prediction used in the RILEM Recommendation is based upon the same principle as used in the Guide.

In 1992, a national standard for determination of durability was published in the United Kingdom [6]. In the standard it is stated that a designer needs to have information on durability to meet the building owner's requirements and to develop a rational policy for the durability of the whole construction. Further, some statements are made saying that prediction of durability is subject to many variables and can not be an exact science. Prediction of service life will normally apply to components and small scale assemblies. Whole buildings and large assemblies are more often one-off designs which make previous experiences of durability less relevant and because of their size it is less easy to test their performance under controlled conditions. In cases where the prediction of service life can not be very accurate, it may nevertheless serve as a useful purpose when items are being ranked in order of durability.

A comprehensive study on methodologies for predicting the service lives of coating systems has been published by Martin et.al. [7]. They present a set of criteria for judging the adequacy of any proposed service life prediction methodology. These criteria include the abilitv to

1. handle large variability in the times-to-failure for nominally identical specimens
2. analyze multivariate data
3. discriminate among these variables
4. fit both empirical and mechanistic failure models to short-term laboratory-based exposure results
5. establish a connection between short-term laboratory-based and long-term in-service results
6. provide mathematical techniques to predict the service life of a coating system exposed in its intended in-service environment

A RILEM Report on durability design of concrete structures has been edited by Sarja and Vesikari [8]. They present a discussion of what they call durability models. These models may be called degradation models, performance models or service life models. The authors have identified the following needs for durability models:

1. technical material development
2. ecological evaluation of materials
3. network level management systems for the maintenance, repair and rehabilitation of structures
4. planning of project level repairs
5. risk analysis of important structures
6. design of a material mix and quality assurance at the construction site
7. structural durability design

In relation to the development of an IS0 Standard for service life prediction, Bourke and Davies have published, a discussion paper on service life prediction [9]. They present a list of essential and/or desirable characteristics of a service life prediction system. No definitive list exists, and the characteristics will be more or less important. In a discussion of advantages and disadvantages of alternative approaches, the authors give the following evaluation of coefficient factorial systems:

Advantages

- recognise the effect of combined deteriorating factors
- permit flexibility as the model can be. developed along simple or complex lines

Disadvantages

- value judgements will still need to be made relating to the relative importance of each deteriorating or protective factor, and guidance on this may not be available
- precise mathematical impact of the adjustments may imply a greater level of conficence in the judgement than the data available would warrant
- unless fairly definite limitations on the number of factors are adopted the process could become very long and complex, reducing its appeal

4 Evaluation of the Factor Method

4.1 General

Up to now there is very little experience from use of the Factor Method as proposed in the IS0 Draft Standard [5]. This is also easily explained for two reasons: the method itself is not much known, and there is a lack of input data for the reference service life (RSL) and for the various factors. If the Factor Method is published as a part of the IS0 Standard for service life prediction, there is a strong need for further evaluation of the method. In the short range, there is need for input data both for the quantification of RSL for various materials and building components, as well as for figures for the various factors in equation **(1).** In the long range, it will be necessary to carry out a more comprehensive evaluation of the Factor Method and the possible quantification of the RSL and the different factors used. The method should be evaluated in relation to the general requirements to service life prediction models as explained in clause **3.** Here are only briefly mentioned some items which ought to be further evaluated.

4.2 Estimation of the reference service life (RSL)

Different methods exist to estimate RSL. The simplest way is to make a guess based on experience and knowledge of actual circumstances including choice of materials and components, climate exposure conditions and maintenance. Alternatively, more specific procedures can be used including various types of testing or statistical data. The most precise procedure for determination of RSL today is the use of the RILEM Recommendation [3]. However, this is also a rather laborious procedure.

Irrespective of the procedure used to determine RSL, it is most important to know what amount of information which has been put into the actual figure. It is important to establish a most general value, and not to incorporate more specific, local experience related to e.g. workmanship, climate conditions and maintenance procedures, since this will be handled by use of the various factors of equation (1).

4.3 Important factors

In equation (1), 7 factors are used to describe various conditions which need to be taken into consideration. These are meant to cover all relevant aspects in a service life estimation. However, in each specific case it will be necessary to ask what are the important factors which can influence the service life of a specific material or component in a specific application. This gives the opportunity to include conditions and factors which have a concrete influence on the service life.

4.4 Necessary number and type of factors

In equation (1), each factor is given by one single number. In the Japan Principal Guide [4] however, in many of the examples the various factors are explained in more detail by splitting into a more specific description of each factor. This gives the opportunity to include specific conditions which are regarded to be of importance for the value of each factor.

4.5 Use of the factors in an equation

In equation (1), the factors are simply multiplied to give one total figure to be multiplied by RSL. However, based on experience or a physical description or interpretation of each factor or the relations between the factors, it may be more correct to combine the factors in alternative ways. Such examples are shown in the Japanese Principal Guide [4], where factors or groups of factors may be multiplied, added or divided. As mentioned in clause 4.4, a more varying use of the factors will contribute to a more correct description of the influence of each factor. On the other hand, it will be necessary to have a defined combination of the various factors and subfactors in order to treat the materials and components in a harmonized way.

4.6 Reasonable span of the values of the different factors

In some examples using the Factor Method in the IS0 Draft Standard, the figures for each factor are varied within the interval 1.0 ± 0.2. In fact, the values 0.8, 1.0 or 1.2 are used. In practical situations, it may be necessary to use other values. The value to be used for each factor has to be based on an evaluation of the statistical variation of the parameter expressed by each factor. The value of some of the factors can vary several hundred percent, and the extreme values can be strongly asymmetric compared to the "neutral" value 1 .O. E.g. this is found for wood materials, based on data from practical use (effect of paint or impregnation, panel profiles, wall construction, etc) [10], [11].

4.7 Relative importance of the factors

As mentioned in clause 4.5, the factors may be combined by multiplication, addition or division. Further, in clause 4.6 it is shown that the value of a factor can vary within hundreds of percent. Altogether, this may give the necessary freedom for variation of the factor values. However, an other way of varying the factors may be to weigh them relative to each other. This can be an alternative way of combining the factors and to express their interrelations. Exponents can be used for the simple factors shown in equation (1), or in more sophisticated expressions as explained in clause 4.5. Use of weighing factors may be of interest in a future refinement of the Factor Method, when more input data and experience with the method has been achieved.

4.8 Uncertainty of the factors

The values chosen for the factors of equation (1) are not exact figures. They are based on experience or probabilistic data, and will in fact have some statistical distribution. It will therefore be necessary to develop some statistical distribution for each of the factors, and a calculation has to be carried out to see how the single distributions altogether can influence on the total outcome of the estimated service life. Due to the multiplication of the factors, the total result is quite sensitive to variations of each factor. As an example, it can be shown that an increase of each factor by 10 % will increase the estimated service life by approximately 100 %, whereas a decrease of each factor by 10 % will decrease the estimated service life to approximately 50 %. However, consideration has to be made on the probability distribution of the final value of the estimated service life. This example also illustrates the necessity of deter-mining the value of each factor as good as possible. Some preliminary studies are being carried out to see how statistical methods can be used to estimate the most reliable mean value and variation of the different factors of equation (1).

4.9 Factor dependency on material or component to be evaluated

When choosing values for each of the factors in equation (1), it is necessary to regard the actual material to be evaluated. E.g. for choosing a value of the factor describing an external coastal climate including sea spray (factor F), it will be important to difference between reinforced concrete and wood. For the first material, the climate mentioned will cause a reduced factor, whereas for wood material the salt exposure probably will cause an increased factor. Similar relations between materials or components and factors may be caused by a specific design of a component or a building, or by a specific indoor climate.

4.10 Important considerations for practical use

As briefly shown in the clauses above, there are several aspects to be taken into consideration when using the Factor Method. The final description of the method and the expression of the equation(s) to be used, have to be a compromise between many requirements and wishes. The method to be published in a standard should be regarded in relation to the aspects shown in figure 1. If the potential users are not convinced that the method covers these aspects to a sufficient extent, it will not be used

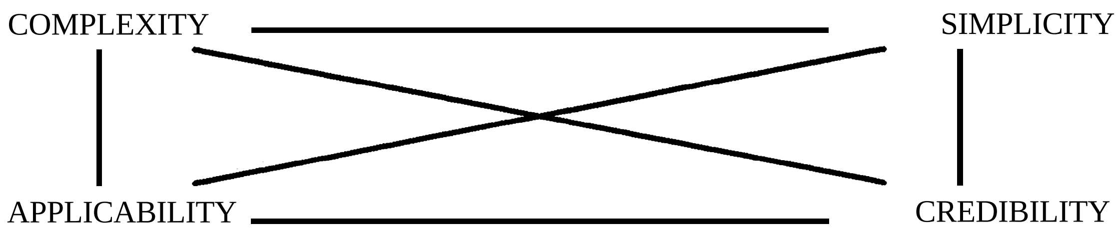

Figure 1. Relations to take into consideration in evaluation of the Factor Method.

5 Conclusions

Over the last decade, there has been an increasing interest of and need for tools to determine service life for materials, components, constructions and buildings. Some comprehensive studies have been carried out regarding service life of specific materials or products, e.g. concrete, metals and paint. An outcome of this work has also been general requirements of methods for prediction or estimation of service life.

The Factor Method has been introduced in an IS0 Draft Standard as a tool for estimation of service life. The method has gained specific interest over the last years, but little experience has been gained by use of the method so far. The discussion in this paper has shown that there are several aspects of the method which need to be further evaluated, in order to achieve a method which is sufficiently reliable and user-friendly. There is also a great need for input data for various materials and components in order to use the method.

More studies are going on in order to develop the Factor Method further, or to get more experience with the method. Such work will be carried out within the joint CIB W80/RILEM-SLM group “Service life methodologies” until the year 2000, or in national projects related to specific materials (concrete, wood) or buildings.

Acknowledgements

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References

1. *The Earth Summit’s Agenda for change - A plain language version of Agenda 21 and the other Rio Agreements.* The Centre for Our Common Future, Switzerland, 1993.
2. *Construction Products Directive (Directive 109/86/EEC).* European Commission, Brussels, Belgium, 1988.

2. *Construction Products Directive (Directive 109/86/EEC).* European Commission, Brussels, Belgium, 1988.
3. Systematic methodology for service life prediction of building materials and components. RILEM Recommendation. *Materials and Structures,* Vol. 22, pp. 3 85-392.
4. *The English Edition of Principal Guide for Service Life Planning of Buildings.* Architectural Institute of Japan, Japan, 1993.
5. ISO/CD 15686 Part 1 *Buildings: Service Life Planning. Part I - General Principles.* ISO/TC 59/SC 3/WG 9 "Design life of buildings".
6. BS 7543 : 1992 *Guide to Durability of buildings and building elements, products and components.* British Standards Institution, London, United Kingdom, 1992.
7. Martin, J. W. et.al. *Methodologies for Predicting the Service Life of Coating Systems. NIST Building Science Series 172.* National Institute of Standards and Technology, Gaithersburg, Maryland, USA, 1994.
8. Sarja, A. and Vesikari, E.: *Durability Design of Concrete Structures.* RILEM Report 14, E & FN Spon, London, United Kingdom, 1996.
9. Bourke, K. and Davies, H.: *Factors affecting service life predictions of buildings: a discussion paper.* Laboratory Report, Building Research Establishment, Garston, Watford, United Kingdom, 1997.
10. Adrian Bennett, Building Research Association of New Zealand, Wellington, New Zealand. Private communication.
11. Jan Steinar Egenes, Gjøvik College, Gjøvik, Norway. Private communication.

Necessary measures to reduce construction waste in Egypt: A model for developing countries

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Abstract
In order to attract foreign investments and increase industrial production, the Egyptian government initiated the construction of some 20 new cities around the old urban centers. Numerous tourist villages were constructed along the coasts of the Mediterranean and the Red Sea to attract European tourists and Egyptian holiday makers. Most of the construction activities that took place in these areas, used traditional methods of construction and traditional materials. As a result of poor construction practices, thousands of tons of construction waste is now polluting these areas which were once virgin environment. Reducing this waste is now a necessity in order to maintain these areas for the coming generations. A national policy should be established so that all concerned parties are aware of the consequences of construction waste and its impact on the environment. This policy should require modifications at the design stage, by adopting new materials that produce less waste during construction, as well as changing the construction methods in order to reduce the waste. Such a plan should not blindly adopt environmental measures taken in the developed world. Third World countries have different priorities in dealing with waste management. A successful policy will recognize this fact and deal with it realistically. Waste reduction in Egypt can be achieved through proper application of quality control measures, accurate estimation of ordered materials, and changes in the traditional design and construction procedures. Applying basic engineering practice, such as thorough geotechnical and geological investigations, will help to avoid constructing new developments on unstable soil, and hence avoid waste.

Training of professionals and technicians and generating a common interest in environmental protection and preservation is essential. It must be recognized and accepted that successful construction projects are those which are not only cost effective, but also less damaging to the environment. This paper looks at the sources of construction waste in Egypt, proposes methods of reducing waste and examines the role of the construction team and authorities in adhering to this policy in all forthcoming projects.

Keywords: Construction waste, concrete, design, building materials, environment protection, training, recycling, developing countries.

1 Introduction

In countries undergoing ambitious development plans, decision makers, are often more concerned with the immediate results than with the long-term outcome. Many of the environmental problems facing the world now could have been avoided had decision makers 50 or 60 years ago been well informed of the consequences of the huge industrial and construction boom that followed the end of the Second World War. Developing countries are going through the same fate now. It is necessary at this stage to sound the alarm to avoid repeating these mistakes.

The developed world has realized the serious drawbacks of having millions of tons of construction waste accumulated over the years. Hence, serious steps were taken towards reducing this waste. These are normally classified under one of the following:

- Increase the use of recycled materials in the construction industry.
- Order more accurate quantities of construction materials to avoid waste.
- Issue environmental legislation banning haphazard methods of waste treatment.
- Observe the strict application of the environmental protection laws by both governmental and public bodies.

In the Third World, the above steps are difficult to implement due to high cost and the more imminent problems that overshadow the environmental protection issue. This paper presents the experience of Egypt as an example to a Third World country suffering from this environmental problem.

In the past decade Egypt has promoted the creation of new urban and suburban communities in undeveloped areas around Greater Cairo, the north coast of the Mediterranean Sea, Sinai Peninsula and the Red Sea shore line. These communities serve as industrial, residential and recreational facilities to replace or supplement the over crowded facilities in Cairo and Alexandria and to open new opportunities for the Egyptian tourist industry. As a result, an unprecedented construction boom has occurred in these areas to meet the current and future demands.

Initially, these projects, especially those in the new cities, were constructed by contractors from the public sector under the supervision of the Ministry of Reconstruction and New Communities (MRNC). Consequently, a certain degree of control was imposed on the construction waste. A recent trend is to encourage the private sector to participate more positively in the construction works in these communities in order to foster competition to benefit the market and the end consumer. Since the private sector is inherently motivated by profit, the damage to the environment caused by the construction waste may be escalated. Many of the projects built in the new cities were developed using traditional design and construction techniques. As a result, many suffered from the traditional problems of poor quality of concrete works and finishes and leaking drainage systems and roofs encountered in the urban areas of Egypt. Construction waste and its effects are problems that require immediate attention, not only to reduce unnecessary cost, but also to preserve and protect the environment in these new communities.

Construction waste increases the cost of a project through the additional cost of transporting the surplus material to and from the construction site, and the cost of repairing the damage caused to the environment by the waste. The later could be quite expensive and should be accurately evaluated. This paper proposes an approach to reduce the construction waste and the damage it causes to the environment.

2. Sources of construction waste

The construction industry is based on team effort. Unless this team is well led, control will be lost,, leading to poor performance. Also, the construction process is a chain of related activities, and a defect in one may adversely affect successive activities and could result in redundant or defective work. This might require the demolition and reconstruction of the defective elements thus resulting in construction waste, delays and additional cost.

Some of the traditionally used materials produce excessive waste during construction. Bricks, for example, produce a large amount of waste due to broken units resulting from transportation, left-over materials and spoiled components during plaster application. Also, traditional formwork with wooden strips cut to fit the required dimensions for cast-in-situ concrete, may soon be spoiled and could not be easily adapted for other uses.

Chemicals newly introduced to the construction industry require special storage methods and have strict expiration dates. These materials, if not handled properly, can produce dangerous waste detrimental to the environment. For example, concrete admixtures, epoxy adhesives, paints, solvents and waterproofing compounds are now commonly used. Due to the remote nature of the sites of new cities, the contractor may be tempted to store larger quantities of materials to avoid shortages in supply. Surplus chemicals and chemicals that have exceeded the expiration date may be dumped on or near the site to save transportation costs. Oils and lubricants resulting from the maintenance of equipment used in road construction and land moving are normally dumped on the surrounding land. It is also common to bum rubber tires to melt bitumen for waterproofing work. Waste is also generated due to over estimation of the quantities of a required material. This is quite common when working with cast-in-situ materials. All this will create waste and hence pollute the environment.

3. Current methods adopted to deal with construction waste

Currently, the methods adopted to deal with the construction waste in the new cities and holiday resorts in Egypt are both primitive and damaging. In most of the cases, waste is dealt with through a waste remover, who is assigned by the contractor to remove the waste from the site. The contractor, the engineer and the project owner normally do not monitor the method of waste disposal. This allows the waste remover to use a variety of dumping methods regardless of their long-term impact on the environment. Often, this waste is used as a landfill material to level depressions in the natural grade profile. This can have costly or problematic consequences, if the backfilled land is used for construction works or some other uses in the future. It can also pollute the environment if the dumped materials are not inert. The effects of such practices on underground water and on the wildlife are detrimental.

4. Methods to reduce waste during the design stage

Waste reduction should be considered during the training of engineers and technicians involved in the construction industry. University education and short courses should offer a focused study of this topic for both students and professionals. Manv countries in the developed world have recognized the link between engineering system demands and environmental protection. This topic is introduced here at a project level, to be used as a model for Third World countries.

4.1. Documentation

The project contract should include specific provisions requiring the contractor to plan his site activities in such a manner to reduce waste. These requirements will form part of the quality assurance program to be implemented by the contractor under the supervision of the engineer This can be achieved through the following:

4.1.1 Contractual obligations

It is advisable to insert clauses in the Contract Conditions which obligate the contractors to preserve and protect the environment under threat of significant legal and financial penalties. It should be required that debris and construction waste be *properly* disposed of in licensed dumps. The contractor should be required to submit with his bid, his plans to minimize waste during the construction period and the method used to transport and dispose of any waste. The owner should review the tenderers' plans before awarding the contract. A tenderer, with the lowest cost and in full compliance with the technical and contractual requirements should not necessarily be awarded the contract if his proposals for environmental protection are not adequate. This is a major change in the traditional evaluation of tenders which requires strong support from the government. The authorities should be the first to apply this concept to establish a standard for by the private sector as well.

4.1.2 Site layout plan

One of the important submissions by the contractor during the mobilization period is the Site Layout Plan. This plan shows the location of temporary works and the land-use intended during the construction period, so that these facilities will not conflict with the permanent works. The temporary facilities shown on the plan should include the site storage areas, waste collection points and dumping yard. The engineer's review of this plan ensures that the contractor has planned efficiently to deal with the construction waste resulting from his work. If the engineer is not convinced of the efficiency of these plans he should reject them and insist on their modification to ensure proper environmental protection .

4.2 Materials selection

The utilization of prefabricated materials rather than in-situ fabrication will reduce the construction waste. This pertains to many aspects of architectural and structural works. The following examples illustrate this concept.

4.2.1 Waterproofing system

Waterproofing used in roofing systems was traditionally applied using an in-situ, built-up, multi-layer system of hot bitumen with reinforcing layers in between. Poor installation of such a system was found by Daoud and Abbas to be the reason for roof leakage in 600 houses in one project in Kuwait [1]. This was the only method available in Egypt until a few years ago. Gradually, prefabricated, modified-bitumen membranes, reinforced with non-woven layers of polyester or PVC, have been gaining acceptance in the market. Four years ago, one or two suppliers were providing this system for a limited number of projects. Now, more than ten suppliers dealing with imported materials from neighboring countries or Europe. Prefabricated membranes have many advantages over the built-up membranes since they have even thickness, require less skilled labor to lay, produce less debris, have consistent quality and can be applied faster. Also, the material is delivered in rolls of known length and width, hence fairly accurate estimation of the needed quantity can be made with minimum surplus or waste.

In-situ built-up membranes are easier to install around openings and are less expensive. However, considering the harsh environmental conditions such as high temperatures and sand storms in Egypt which may prevent adequate supervision during material application, prefabricated membranes will reduce the likelihood of defects in the waterproofing layer. This will reduce waste through minimizing the possibility of defected application or damage to underneath works due to leaking water.

4.2.2 Internal partitions

Traditionally, fired-clay brick walls were used for internal/external partitions in Egypt. Until fifteen or twenty years ago, this was the most commonly used material for this purpose. Concrete blocks, sand-lime bricks, lightweight-foamed concrete and other types of blocks became available due to the prohibition of using clay cut from cultivated land for the purpose of producing bricks. Almost all residential dwellings are built using reinforced concrete skeletons with unit blocks used only as infill. Damage to five percent or more of the blocks is normal during transportation and handling. This can increase to ten percent for extended transportation to new cities or to 25percent for certain types of blocks, such as concrete blocks, or due to double handling. The waste in brick work was found to range from 11 to 23 percent in Brazil, which is typical of developing countries, while waste in the Netherlands was only six percent [2]. Construction of block walls can be quite messy during mortar mixing and application, producing large amounts of waste. Furthermore, these block walls impose additional loads on the concrete structure which results in heavier elements at higher cost.

The use of lightweight partitions made of gypsum boards has gained acceptance in the USA and Europe. A few hotels and office buildings in Egypt have been built using this system. The system is less popular in residential units due to sound transmission. However, board partitions are lighter in weight which reduces the total load on the foundations, easier to control during construction, require no plastering work due to accurate alignment, produce less debris, do not require highly skilled labor for installation and require less labor during construction. Furthermore, the leftovers can be recycled, however, this is not feasible yet in Egypt since recycling will be quite expensive. Like all prefabricated elements, the quantity required for use can be accurately estimated to reduce the cost of transportation and waste resulting from surplus materials.

Due to their poor resistance to forced entry and, relatively higher sound transmission, lightweight partitions should be limited to internal partitions in the dwelling. A sound insulation layer of mineral wool can be inserted in the cavity of the dry partition to reduce sound transmission. The poor resistance to moisture was another disadvantage of the system which rendered it unsuitable for bathrooms and kitchens. However, moisture-resistant boards are now available in the market and are gaining acceptance for use in wet areas.

4.23 Load-carrying system

As mentioned above, most of the structures built in the new cities and tourist villages are made of reinforced, cast-in-situ concrete skeletons. The use of such a system in these remote areas is bound to result in more defective elements than normally experienced in other construction sites. Due to the remoteness of the site, the engineer's supervision of contractor's work is reduced, as well as contractor's supervision of his laborers. As a result, defects in concrete skeletons are more likely to occur. The concrete will deteriorate at a fast pace due to its exposure to humidity and salts and will be costly to repair or replace. Beside the resulting debris, waste materials in large quantities are common with cast-in-situ concrete. In a study by Soibelman et al. [3], 12 percent of the concrete purchased in Brazil was wasted. The waste for cement alone was 46 percent while for sand it was 3 1 percent. These materials are normally dumped on the project site or on neighboring sites. The pollution of the Mediterranean Coast by discarded concrete is only one example of the possible damage caused during the construction of tourist villages.

The use of precast/prefabricated units produced in precasting yards ensure higher quality, less waste and less pollution. Using load bearing walls instead of reinforced concrete skeletons with in-fill walls will ensure more durable construction with greater resistance to the aggressive environment to which sea front structures are subjected. This may also be more cost effective and requires less time for construction. It is ironic that in many of the summer houses built on the northern shore line, limestone veneer from neighboring quarries is used to clad the external facades. It would be more practical to use this stone as a carrying element especially for one and two story buildings. Furthermore, load-bearing wall systems will produce less waste during construction since the surplus materials (blocks) are reusable elsewhere.

4.2.4 Recycled materials

It is advisable to consider the waste problem from an economic as well as environmental viewpoint. Economic benefits can be achieved if the construction waste can be recycled to produce fresh usable materials. This concept should be implemented by designers and enforced through the bylaws issued by the MRNC for the new cities. Until recycling is carried out on a large scale, the cost of recycled materials in Egypt may be uneconomical.

5. Methods to reduce waste during the construction stage

A wise contractor will do his best to reduce waste in order to maximize his profits. However, contractors who are accustomed to a certain way of conducting their work cannot reduce waste unless they modify or change these traditional ways of construction. Following are some examples of the sources of waste arising from the traditional construction methods, and the suggestions to reduce the resulting waste.

5.1 Concrete formwork

The traditional method of concrete formwork is used throughout construction sites for dwellings and residential apartments The sheathing is made by strips of wood, 10 to 15 cm wide, nailed together and jointed by clamps and nails. The shores are made of wood poles clamped together or tied with ropes. The wood not only wears quickly, due to its physical vulnerability, but it also results in considerable waste during fabrication [4]. The resultant pieces of damaged wood are normally piled on the site or burned. This formwork could be reused four to five times with good results, but often it is used more times to save on cost, which reduces the quality of the concrete surface requiring thicker plaster work and resulting in more waste.

Prefabricated formwork is made of plywood, metal, metal-framed plywood faced or other materials. Steel rods are used for scaffolding and props. This type of formwork is expensive, but is easier to use and adapts to different shapes. Furthermore, it can be reused up to eight times with continuous good quality. It is also faster to erect and dismantle, easier to store, and above all, produces much less waste. In projects with repeated units, prefab formwork can expedite the concrete production with consistent surface quality and savings in the cost of finishes.

5.2 Tight quality control

Construction waste can be reduced by adopting a quality control (QC) program to ensure the quality of the final product in accordance with the specifications. This will require implementing tight control procedures ensuring the quality of the end product and hence to minimize removing or replacing defective elements, wasted time, cost and unwanted materials. Unfortunately, this approach is not yet well recognized by many owners, consultants and contractors.

In the Third World, in general, project owners do not appreciate QC if it results in higher cost. Consulting engineers will not recruit specialist QC personnel because they are expensive; instead they often assign this responsibility to the least experienced staff member on site. For projects in new cities, contractors depend upon the fact that the site is remote and often assume that substandard materials and workmanship will go unnoticed. Hence, they lower their cost, at the expense of quality, to increase their chances of winning the contract. As long as these principles dominate the construction industry, and in the absence of government regulations to impose proper QC, poor quality will prevail, resulting in significant waste, surplus and unwanted materials.

6. General requirements for the Egyptian market

6.1 Training

Though McDonald claimed that site staff in Australia required little training to minimize waste [5], this may not be applicable in Egypt. Training programs for professionals and laborers involved in the construction industry are required to improve the standard of their work and reduce site defects and hence waste. This calls for a national scheme to be adopted by professional syndicates and labor unions. Training should concentrate on QC procedures, quality assurance measures, new trends in the construction business, modern management procedures and performance of building materials. Specialized training centers equipped and staffed adequately are needed to provide this service under the supervision of professional bodies and a national committee for advanced training. On-the-job training should concentrate on methods to separate waste for reuse, correct orders of materials to ensure accuracy, and in the future, separate waste for recycling. This could be achieved through regular site meetings.

6.2 Quality control of manufactured materials

Since many of the materials used in the construction industry are now manufactured locally, it is important to provide quality control during the manufacturing process. Consistent quality and adherence to acceptable standards should be maintained. Often local products do not satisfy these requirements and lead to abortive work in replacing defective elements and a waste of money and material. The development of appropriate local standards and well equipped laboratories should be encouraged. Translating foreign standards to be adopted as Egyptian standards is not practical and could be misleading: often these are poorly translated and out of date by the time they appear on the market. However, their is no harm in adopting valid foreign standards if appropriate to the local environment. The lack of well equipped laboratories to test these products would invalidate any attempt to apply QC procedures in Egypt. Several tests cannot be performed locally and samples must be sent to Europe for evaluation. This is not practical and is time and cost consuming.

6.3 Reduce tenants modifications

Many of the apartments constructed by the government are modified when their tenants move in. These modifications are due to poor quality of materials installed, unrealistic design that does not satisfy the tenants' backgrounds and, in a few cases, the need to distinguish one's self from the neighbors. Major reconstruction work would result in huge waste. It would be more economic to study these modifications and adopt them in new designs from the beginning or consult the tenants before finalizing the design.

6.4 Conduct comprehensive field survey

Since the new cities are built in remote areas, comprehensive geotechnical and geological studies are needed before the site is allocated for construction. This will reduce any possible waste due to removal of constructed facilities built on unsuitable soil. Several cases have been reported of construction of new cities taking place on questionable soils that suffer from serious defects. A whole city in upper Egypt (The New Minia) [6] and several neighborhoods around Cairo [7] could be removed due to cavities in the soil underneath or other soil defects.

7 Conclusions

The subject of reducing construction waste must be addressed in all construction projects and, in particular, those to develop new cities and seaside resorts. In order to avoid long-term damage to the environment, the current haphazard procedures of waste disposal used in inner cities should be avoided in new locations. It is the duty of all those concerned, including the government offices, local authorities, consultants and contractors to prepare a national plan addressing this issue. The environmental considerations are important criteria, not only during the construction stage, but also during the early planning and design stages. It should be understood that nothing is free. The owners, including the concerned governmental departments, should expect a higher initial cost as a result of these environmental measures. However, this cost should be weighed against the hazards to the future generations of these new communities if such measures are ignored or deferred.

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9 References

1. Daoud, 0. E. K. and Abbas, M. (1990) *Assessment of a Roof Leakage Problem in Kuwait*", Inter. Journal of Forensic Engineering, Vo12, No. 4, pp. 437-447.
2. Bossink, B. A. G. And Brouwers, H. *J.* H. (1996) *Construction Waste: Quantification and Source Evaluation,* Journal of Construction Engineering and Management, ASCE, Vol. 122, No. 1, pp. 55-60.
3. Soibelman, L., Formoso, C. T. And Franchi, C. C. (1994) A *Study on the Waste of Materials in the Building Industry in Brazil,* Sustainable Construction, Proceedings 1st Conference. Of CIB TG 16, C. J. Kibert, editor, Ctr. For Construction and Environment, Fla., pp.555-563.
4. Karshenas, S. (1997) *Strength Variability of Conventional Slab Formwork Systems,* Journal of Construction Engineering and Management, ASCE, Vol. 123, No. 3, pp. 324-330.
5. McDonald, B. (1997) *Building Construction Case Study, Fletcher Construction Australia*, Internet site, www. cfe. cornell. edu/wei/cwei/build. html.
6. Abdel Tawab, S. And Ibrahim H. A. M. (1991) *Unfavorable Geologic Setting of the New Minia City, Upper Egypt,* Journal of Engineering and Applied Science, Vol. 39, pp. 421-429.
7. Moustafa, A. R., El-Nahhas, F. And Abdel Tawab, *S.* (1991) *Engineering Geology of Mokattam City and Vicinity, Eastern Greater Cairo,* Bulletin of Engineering Geology, Vol. 31, pp. 327-344.

WASTE MANAGEMENT IN THE CONSTRUCTION INDUSTRY

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Abstract

A detailed study of the application of waste management to a single multi-million dollar residential project in Queensland is described. The study incorporates the assessment of a current on-site waste management operations plan and a questionnaire survey of the construction workers involved to ascertain their involvement and attitude towards the processes.

Keywords: Landfill, recycle, reuse, waste disposal, waste management.

1 Introduction

It is estimated that 13-30% of all solid waste deposited in landfills worldwide comprises construction and demolition waste[l] with a 1:2 ratio of construction to demolition waste[2]. In Holland, for example, this amounts to around 4.25 thousand million tonnes of construction waste each year. Insights into the causes of the generation of waste in construction projects are growing however[1][3] and waste management policies have been developed in Europe for example [4]. In response to increasing awareness of the environment, the Australian Government has established several strategies to implement ecologically sustainable development (ESD). One major arm of ESD is the National Waste Minimisation Strategy, which has set a target of a 50% reduction in waste, 15 % of which is from building and demolition work, going to landfill by the year 2000 based on 1991 standards.

This shift in social attitudes towards 'environmentally friendly' values together with the possibility of future state and local government legislation or taxation on the lines of the UK Landfill Tax[5] suggests that strict guidelines for commercial ventures will soon be introduced. In October 1997, the Queensland Government produced Proposed Waste Management Legislation Public Consultation Documents. As a result, it is becoming necessary for organisations to establish some form of environmental management system.

Previous studies in this field suggest that high rates of success may be obtained by implementing waste management strategies in the construction industry. Other defined benefits include financial gains, through the sale of salvaged products or reduced disposal costs, and environmental benefits[5][6][7][8].

This paper reports an investigation of the current Waste Management Strategy implemented by a major Australian contractor (1) to determine the efficacy of the strategies in use, and (2) to evaluate the practicality and desirability of further developments.

2 Casestudy

2.1 The project

The researchers studied the waste management methods employed by a major Australian construction company and their operation on one construction project in the Brisbane area of Queensland. The project was a Brisbane inner city apartment project, completed in October 1996. Access to the site did not present any problems for coordinating through traffic, as the site was located at the end of the local traffic area. The construction works consisted of two (2) residential towers of five (5) stories each featuring high quality apartments, underground car parking and landscaped surrounds. A permanent crane established centrally serviced both towers. Throughout the site were designated lay-down areas for the storage of goods, site accommodation and waste bins as required.

The project served the purpose of being a pilot project for the contractor in regards to waste management. It was intended to provide a comprehensive trial of waste management procedures and did so successfully. There were several features of note: no previous data or information was available to draw on; personnel were unaccustomed to waste management procedures; there were restrictions on labour availability and time; and there was no material hoist on-site which limited the capacity of handling segregated waste containers. In addition, the contractor had already commissioned and received a consultant report for a Waste Management Strategy for a recent brewery project and the principles noted in this report were also implemented on the case study project. These issues concerned: bin positioning, use and identification; the workers induction program; the provision of a list of local recyclers; and the collection of statistical information.

The contractor drafted a Waste Management Plan (WMP) clearly defining its policy, staff responsibilities and procedures to be adopted and designed to meet and exceed the company's current obligations under the Environmental Protection Act 1994. Although some guidance was provided to develop ways in which to avoid or minimise waste, no specific guidelines were established in work process optimisation, material planning, on-site training and methods of effective and efficient reporting of waste quantities.

The Project Manager correlated the trades represented on the program with the major waste streams, to establish which products presented an opportunity to recycle. Anticipated wastes suitable for recycling included concrete, masonry, timber, metals, and plasterboard. Other waste not suitable for recycling and disposed of as general waste incurred normal disposal charges. In the event that any unacceptable contamination of waste occurred, and disposal at the Brisbane City Council transfer station was required, an additional charge of $55 per tonne was incurred. Hence, handling methods were considered crucial to the effective disposal of waste with the aim of maximising recycling to benefit the environment and reducing disposal costs.

2.2 The waste contractor

A specialist waste transportation firm was commissioned for this project. On this project the specialist's primary responsibilities included the provision of waste collection bins and labelling of the bins to suit the waste streams identified in the contractor's WMP.

Early negotiations with the specialist enabled the planning of suitable methods of disposal of various waste streams and allowed the setting of a fee scale depending on the items removed. The contractor's WMP stipulated that waste material could become the property of the waste removal contractor on collection from site, and that any rebates paid on recyclable products should be made to the account of the waste removal contractor.

The task of monitoring was delegated to the specialist waste handler and included data collection and the subsequent collation and analysis. The driver of the waste bin service truck was responsible for determining where the waste was to be delivered to and whether it was contaminated or not. If the waste was considered to be contaminated the site supervisor was informed and asked to co-sign the delivery docket to indicate agreement that it was contaminated and would be unsuitable for recycling.

At the point of pick up the driver recorded the date, bin size, waste product type and the place of disposal. This method of data collection produced only approximate results. There was concern about the accuracy of data available for this study because of the lack of awareness by drivers of the type of product to be collected and where it was to be disposed.

The waste analysis undertaken by the waste specialist for the contractor provided a month by month breakdown of wastes removed from site and information regarding the specific waste streams targeted for separation and recycling. Calculations were based on weights and provided monthly and cumulative totals and percentage ratios of the respective wastes.

2.3 Site observations

During the course of the project several site visits were conducted during which observations and general conversations with site management were noted. Some of the more important discussions covered waste types, waste handling methods, programming, project types, cost implications, education and human influence on waste management. Observations made in relation to waste management during site visits noted signs and notices, bin contents and waste handling procedures, control issues and site layout.

The waste handling method on-site began at the work area, where wastes were stockpiled and then removed by labourers daily into a small collection bin suspended by the site crane at the edge of the working deck. The crane was used for approximately one hour per day to carry out this clean-up operation. Discussions indicated that this method of waste collection must be analysed closely prior to implementation, to ensure that a particular type of project was compatible with waste handling methods proposed.

Disposal of the four key material types were analysed in detail:

Timber. The majority of timber waste was generated during the formwork process. Primarily, waste occurred from work undertaken on the materials to make them suit the required shape and size of the formed concrete, and due to rough stripping methods. Good planning by the subcontractor to m&e formwork 'fit' with minimal modification and better care during the stripping of formwork would have contributed to reducing waste. Waste timber products generated by formwork were deposited into bins at the work area since there was easy crane access to place bins onto the working platform. So a high proportion of material could be separated for recycling. Problems included the careless contamination of timber with foreign substances such as masonry or other waste at the ground floor level. The whole load of timber then became non-recyclable and forced the waste contractor to dispose of large quantities of timber waste as general waste.

Masonry and plasterboard. These were used for partitioning works. During construction, a majority of the masonry blocks ordered and used were standard sizes available from the manufacturer, consequently waste was avoided to a large extent. Waste during construction occurred when blocks remaining from various work areas were left over and no effort was made to collect and use them elsewhere. Often these were simply disposed of during clean up. Other minimal waste occurred through broken blocks or due to unusable off-cuts. Plasterboard was susceptible to damage both during handling and also once in place. Planning of sheet sizes required at various stages during the project minimised waste and was carried out by the Project Manager in conjunction with the plasterboard subcontractor and plasterboard manufacturer. Although a bin was provided to receive concrete and masonry waste, no materials of this type were successfully separated. All concrete and masonry waste on this site was disposed of as general waste. Plasterboard waste was collected in stockpiles near the work areas. During the clean up process, the waste was deposited into suspended crane bins as described for metal products. Due to the large volumes of this material segregation was relatively simple. Therefore a substantial amount of plasterboard waste was successfully separated. No recycling opportunities existed for plasterboard on this project, as the manufacturer did not have the facilities to reprocess this product. However, as plasterboard was classified a potentially hazardous waste by the Brisbane City Council and required disposal at special landfill sites, the isolation of this material reduced disposal costs.

Paper Products. A large amount of paper packaging of goods on-site had to be appropriately disposed of. Packaging itself was not significant during the product use phase as it was generally intended for disposal and acted as a protection to goods during handling. Paper products derived from packaging were to be deposited into a bin provided by ***Visy Board*** at the ground floor. Again, sorting difficulties on each floor meant that very little paper products went into the designated bin and were mainly disposed of as general waste.

Metal. Metal waste was mainly derived from reinforcement, steel partition framing and roofmg off-cuts. Reinforcement waste was minimal and primarily resulted from miscellaneous spare items left after the completion of the works. Metal roofing waste was due to off-cuts and modifications made to sheet materials and flashings to suit roof penetrations and geometry. Metal stud waste was attributed to the requirement of size modifications to suit the application. The metal scrap bin was centrally located at the ground floor level between the two apartment buildings. At rubbish collection time, all refuse was collected into one suspended container at each floor level by the crane. Consequently loading work was hurried in order to minimise crane time, and various waste streams could not be sorted prior to placing in bins. Therefore, only large and easily separable metal waste was placed in the scrap metal waste bin. Valuable waste such as copper and aluminium was retrieved and taken off-site by the subcontractors and did not contribute significantly to metal waste. The remainder was disposed of in the general refuse bin.

Waste types contributing to a majority of the bulk refuse were plasterboard and formwork scrap. When building products were inexpensive, as was the case with plasterboard, little consideration was given to waste minimisation. In the case of formwork, which was not a cheap product and yet still produced high quantities of waste, the reduction of waste required closer supervision.

Human influence on the success of a waste management plan was apparent as it was the work-groups, which had the final control over the waste handling process. The introduction of Waste Management has been viewed in a light similar to Quality Assurance and Workplace He&h and Safety, which are now generally accepted but each required time before becoming completely effective. Generally, people were willing to contribute positively to the environment but it has been difficult to change habits and culture. During discussions with site management, it was mentioned that the younger generation seemed to accept waste minimisation readily whereas the older generation was a little more difficult to convince. Perseverance and continually updated training will, some would hope, influence construction workers positively in due time. Also of influence may be stricter contractual obligations with possible penalty charges for non-compliance. Alternatively, a system promoting a spirit of competition and enthusiasm using incentives may provide the appropriate motivation.

Colour coded notices were placed at various strategic locations on the site including lunchroom walls and the notice boards. However, the effect of waste management notices and signs was lost amongst other general information. Possibly, brighter displays isolated from general news and advertising bulletins may have attracted more attention. The notice itself was clear and easy to understand and should have served as a good reminder of the waste separation requirements established on site. The main waste bins had easily identifiable signs clearly displayed on the appropriate bins at most times. Occasional problems occurred with the correct labelling of the bins as the signs were removable and were shifted around when the bins were picked up by the trucks. All people involved should have taken greater care in handling the bins or depositing waste, to make sure the correct sign was clearly displayed.

Upon examination of the bin contents it became apparent that there was a general disregard for placing the rubbish in the proper bin. General rubbish contained materials that could have been separated with minimal effort. The difficulties of controlling waste segregation at all times became apparent during the distribution of the questionnaires around the site. Work was carried out throughout various areas of the project and workers were difficult to locate. Therefore, it was difficult for one person to oversee the compliance of waste separation and workers' attitudes were such that they could not be relied upon to monitor themselves.

3 Questionnaire survey

The key element in the success of a Waste Management program is the involvement, commitment and perception of construction workers on the project. To determine the influence of the key elements amongst workers, a questionnaire was prepared to obtain their general views regarding the principles of waste management and to obtain background information regarding their knowledge of the process. Seventy seven forms were distributed over the site during two survey periods, and a total of thirty nine were returned, representing a response rate of 51% .

In the staff group analysis, the belief that waste from construction works could affect the environment was generally high across all staff levels. Distinct differences, in the understanding of the waste management processes implemented on this site however, occurred between employees and senior site personnel such as leading hands / foremen and managers. Even though both groups had equal quality training, results showed a higher degree of comprehension among subcontract employees than site management. A conclusion which may be drawn from this is that the lack of interest by leading hands and foremen reflected in their disregard the WMP, as they do not consider it a vital component in producing their work cost effectively.

Analysis of various trade groups showed that a majority of subcontract employees considered that they were supervised for less than 25% of the time. Awareness of environmental issues by major waste producing trades was high indicated by the 85.7% understanding that building waste affects the environment, and a 61.9% belief that waste products from their particular trades could be recycled.

For the major waste producing trade of plasterboard, the education and knowledge segment of the questionnaire indicated only an intermediate level of understanding of the waste management process. This result indicated that the subcontractor’s personnel accepted little personal responsibility for waste disposal. Furthermore, a large portion of the plasterboard trade indicated that they had not received any training in waste management. In contrast, a high percentage of the masonry trade indicated that they had an understanding of the waste management process and that it was explained to them. Even though waste generation within the masonry trade was minimised through efficient ordering and material use, the nil success rate indicates that improvements could be made. Perhaps accountability and clean up supervision needs to be upgraded for this trade. Other trades indicated a higher level of understanding of the waste management process. However, the survey showed that part of the plumbing trade group felt that the explanation of the process was not comprehensive enough. Possible explanations for the apparent poor comprehension of the waste management process on this site could be attributed to lack of interest during the site induction, poor recall and low understanding by the workers or because the waste management segment was not presented clearly during the induction process.

Overall, the correlation between the proportion of waste produced by the various trades and the levels of supervision, awareness, knowledge and perception was inconclusive. However, there is some indication that poor results in the plasterboard trade were due to a lack of understanding of the WMP.

The open parts of the questionnaire sought to attract suggestions and comments regarding waste reduction and separation. The results indicate that waste segregation procedures were followed early in the project but that methods became lax as the project proceeded. The comments suggested that to sort rubbish at the point of creation would require more bins which must be clearly labelled and available on each level. It was suggested that additional time should be allowed for clean up and that clean up supervision should be provided at set times in various areas.

A problem that was envisaged with the method of segregating waste at the point of creation concerned the space needed for the various bins required on the working platform. This suggestion however is debatable as waste stockpiles around the work areas consume space and space requirements for a bin are less than for a stockpile of rubbish of the same volume. Also, mobile bins enable better handling of the waste at clean up time and can be moved if they get in the way of works whereas a stockpile of rubbish requires a somewhat greater effort to be moved.

The facilities indicated as being required included more accessible bins and clearer marking on those receptacles. Also mentioned was the requirement for more effort and common sense by the workers on-site and that this be promoted by additional training.

The question of reducing waste was interpreted in two ways, the waste creation process and the waste disposal process. The waste creation processes highlighted the need for an increase in workmanship skills, tighter ordering procedures and reduced packaging. These were previously mentioned as key factors in reducing waste by prevention. It is obviously an area that subcontractors and manufacturers should address and, if done properly, could have financial benefits.

The waste disposal process indicated the requirement for more accessible bins to assure better waste separation to allow recycling. Also noted was the fact that the subcontractors often took financially viable scrap waste home, which resulted in a reduction in the amount of waste on site but with little value remaining in the segregated products. For example, the contents of the metal scrap bin mainly consisted of scrap steel of minimal value.

4 Conclusions

The results of this case study suggest two key criteria, training and process optimisation, for the success of a Waste Management Strategy on a construction site.

Training. Site training of the workers is considered as the key issue to ensure the operation of a successful waste management program on site. The survey of workers indicated that on site training was carried out and a high percentage of the workers understood the procedures. Some indications were given that training in the procedures of waste management were not comprehensive enough and that there may have been a lack of interest during the induction process and that poor comprehension and recall may also have attributed to a lack of commitment to the process. It is suggested, therefore, that training includes a more detailed explanation of the processes during the induction with an emphasis on getting the worker involved in the process and encouraging self monitoring by highlighting the benefits of the program and the way in which the worker can contribute. Finally, to conclude the induction, a worker could be asked to complete a brief questionnaire and sign a declaration of understanding.

Process optimisation. The process of waste handling is seen as a critical issue in that it affects the overall costs of the system and has a large bearing on the success of the program. Costs can be minimised by reducing handling time and labour, and the best way in which to achieve this has been determined to be waste separation at the point of creation. Although training can encourage participation by the workers in the program, site facilities must be provided to ensure success and the site itself must be suitable for the program. To facilitate the best results bins should be placed near the work areas and should be suitably tagged. Workers then have the opportunity to place waste directly into bins thereby eliminating the need for a labourer to carry out this work. The resulting reduction in waste handling, time and effort as well as encouraging workers to keep a cleaner and safer work environment should lower costs. To facilitate this outcome the waste coordinator should conduct an analysis of the site conditions and the wastes derived to determine the most appropriate methods.

A program forecasting waste streams should be developed by the waste coordinator. This forecast will enable the arrangement of a suitable waste handler and the appropriate main waste bins. Where no waste recycling facilities exist, waste should be deposited into general waste bins.

To monitor the progress of waste management on-site data should be collected regarding the waste types and quantities removed from the site. Thus, the early detection of any problem areas can be identified and the dependence upon data from the waste contractor reduced. This data can then be analysed by site administrative personnel as shown in previous sections of this report.

Waste avoidance and reduction were identified as the most beneficial methods of waste management on a construction site. Waste management requires the cooperation of the builder and the subcontractor to plan material requirements and allow adequate and safe material handling and storage on-site.

5 References

1. Bossink, B.A.G., Brouwers, H. J.H., 1996, Construction waste: quantification and source evaluation, *J Const and Engrg Mangt*, ASCE, **122**(1).
2. Bossink, B.A.G., Brouwers, H. J.H., Kessel, R.A.van, 1996, Financial consequences of construction waste, *Proc CIB* W98 Beijing int conf, Oct, 1-6, ///L | /BEIJING.. .0-129/122/ p122.htm
3. Gavilan, R.M., Bemold, L.E., 1994, Source evaluation of solid waste in building construction, *J Const and Engrg Mangt*, ASCE, **120**(3) 536-55.
4. Van Dessel, J., Vyncke, J., 1995, The European policy on the management of construction and demolition wastes, ECOTOP'95, 4 May, l-8.2.
5. Trevorrow, A., 1996, Construction waste: an opportunity for profit? *Proc CIB* W98 Beijing int conf, Oct, l-6, ///L | /BEIJING/papers/160-169/169/p169.htm
6. Alford, M., 1996, A study in cost effective waste management, Research report, Queensland.University of Technology
7. SKM, Sinclair Knight Merz Pty Ltd, 1996, Waste management strategy - Construction and demolition materials, 22 Jan.
8. Heino, E., 1994, Recycling of construction waste, in Sustainable construction, C J Gibert, *Proc*, 1st int conf, CIB TG 16, 6-9 Nov, Florida, U.S.A., 565-71.

INIES - A framework to compile information on building products' environmental quality

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Abstract

INIES is a set of grids intended to document building products' environmental quality (EQ). It is based on a merging of life cycle analysis (LCA) and risk analysis (RA) into a semiquantitative approach. INIES provides general information on EQ as it is available and gives status indications according to the RA steps (hazard identification, risk assessment and risk management).

INIES has been developed and successfully applied within the context of a large scale public funded project involving many types of actors in the construction domain and it is now being experimented as a basis for the introduction of products' EQ information in French construction standards and technical assessment procedures.

Keywords: Life cycle analysis, risk analysis, qualitative, environmental quality, INIES.

1 A view on LCA from theory and practice

From our experience of the theoretical and practical aspects of environmental quality (EQ) evaluation on all types of building products with various partners like manufacturers, general contractors, architects, public bodies, professional associations, etc. we have learned that products' (and buildings') EQ are viewed as a risk of non conformance to legal standards and societal demands.
The true question asked is to get insights on the environmental and sanitary risks associated with building products and how to manage them.

1.1 LCA as a tool for risk assessment

Life Cycle Analysis (LCA) has now become a classical tool for product environmental quality (EQ). According to the new IS0 framework for LCA [1], LCA is defined as an iterative improvement process undergoing the following steps (called "elements" in IS0 language) :

1. Goal and scope definition
2. Inventory analysis (LCI)
3. Impact Assessment (LCIA)
4. Interpretation

In practice, claims for a simple list of "green products", "preferred products", etc. are commonplace. We interpret them as an expression of EQ conscious actors' anxiety and willingness to get quick answers to their question, because they feel like they lack a conceptual framework encompassing also their usual points of concerns like products' technical capabilities and costs and also their legal, social and cultural context.
This is a particularly prominent point when dealing with building products which are intended to be included into a building, i.e. a living and lived-in complex context.
Also, practices like restriction of inventory boundaries to a minimum, not performing impact assessment, and devising "translation" schemes to get simple synthetic results out of multiple-pages ecoprofiles – like [2] for example, may be interpreted as a tentative reorientation of the current LCA model towards actual and practical points of concern.
On the theoretical side, as discussed in [3], subjectivity takes an increasing importance as an LCA progresses through its elements.
In our opinion, the root cause is that, in the meantime, the LCA is moving closer to the complex outer reality of interwined natural and industrial ecosystems and actors – which is what incidentally triggers the intrusion of subjectivity. This should not be a problem providing that all claims for absolute, definitive and numerical values of a product's EQ are abandoned [4], but this point is only beginning to make its way into the LCA theorists' community. This is illustrated in a recent paper from [5], for instance.
Hence the biggest problem with using LCA to answer building products EQ questions is the widening gap between its outputs – and time requirements, and the complex and broad context of the reality in which some kind of decision-making is taking place and is calling for insights on products' EQ.
Hopefully will the IS0 14000 framework gain increased recognition in the future and will provide this lacking framework. But it must be recognised that it is not a fact yet.
Also the IS0 14040's interpretation element should help putting all results back in perspective and integrating them into a global context for decision. But this element is

still in its early infancy and probably requires new concepts and tools, of which few have been proposed so far [6].

In our opinion, there are several reasons why the gap is currently widening.

The first one is that LCA is capitalising on old elements to move to new ones – from LCI definition to LCIA for example, thus constraining more and more its outputs' format and scope to a point where their usefulness for professionals can be questioned. Put simply, in some respects LCA is evolving as a independent science and seems to forget its initial targets in the process.

The second reason is that the claimed scope of LCA is comparatively wide with its actual capabilities. We do use LCA a lot, but we restrict this use to situations where detailed information are required to answer very precise questions; testing the pros and cons of a product manufacturing process change is a typical situation perfectly suited for LCA.

The third reason stems from the fact mentioned earlier that actors want a risk analysis of building products. As will be discussed below, this procedure is not exactly in the same line of thoughts as LCA.

1.2 Risk analysis

Risk analysis (RA) is a three steps procedure [7,8]:

- The first step is to perform a large review of the hazards implied. This is the *identification* step.
- The second step of RA is the *assessment* of the risk related to a given hazard, i.e. the production of a measure of its probability of occurrence and of the severity of its consequences.
- The third step is the *management* of the risks assessed at step 2.

One clear advantage of this approach is to make a separate task out of risk management issues. Indeed, some risks can be judged acceptable by some actors but not by others.

Although simplified numerical models exist for RA [7], their applicability to EQ problems seem inappropriate to us because EQ is not a technical issue only, but rather an ethical topic that will be openly discussed in not technically oriented communities and institutions as well as by engineers.

As discussed in [8], to successfully assess the risks of a problem with numerous stake holders and global implications like building products' EQ problems, the "minimal scope" is already wide enough and is outlined in Tableau 1.

[8] also gives recommendations for the presentation of the results in order for an RA to be successful – i.e. to actually provide usable answers to the questions asked. These constraints have mostly to deal with transparency on assumptions made, indications of possible bias, uncertainties and their consequences and of limitations on the review depth and results significance, etc. Also to be included is a written summary statement.

1.3 LCA vs. RA ?

Although it might be argued that RA is the purpose of the impact assessment element, there are significant differences of scope and approach between RA and LCA. These differences partly explain that the later is not fully functional today.

Firstly, it should be obvious from Tableau 1 that LCA *alone* is not able today to provide the data required to perform RA correctly.

Indeed, considering "all feasible options" requires a technical survey of existing and planned alternatives; considering "all major consequences" calls for a highly complex prospective study of the global effects of what can be considered as negligible differences between alternatives; considering "all sources of uncertainty" goes far beyond all numerical enrichments discussed today to implement sensitivity analysis in LCA [9] and finally, considering "all reasonable values" is new to an important part of the LCA research community.

Consider all feasible options	Consider all sources of uncertainty
Modify wants	In scientific knowledge
Modify technology	In society's values
Prevent initiating events	In decision-making methods
Prevent release	In implementation
Prevent exposure	
Prevent consequences	**Consider all reasonable values**
Mitigate consequences	
Consider all major consequences	
Economics	
Environment	
Societal resilience	
Equity	

Tableau 1 - Minimal scope for a risk analysis, from [8]

Secondly, LCA alone is not able to comply with the transparency and clarity of conclusion requirements, partly because some issues have not been sorted out yet and still retain researchers' attention – data quality for example, but also because LCA is always trying to quantify things, which is an incredibly severe constraint when trying to follow such requirements.

An enlightening consequence of this situation is the comparatively poor conclusion chapters found in most intensive and time consuming building products' LCAs publicly available today.

We do not advocate a solution where LCA would be further developed to finally encompass RA - except possibly as the basis the newly born interpretation element, but we would rather favour a solution where the existing LCA and RA frameworks are merged together in a practical way.

2 Merging LCA and RA at an acceptable level

So now, how can LCA be useful within a risk assessment procedure ? This question can be divided into a concept matching problem and a data matching one, both of which are addressed below.

At that point our first objective is to develop a simple framework, i.e. one that can be easily and cheaply deployed. We also aim at preserving as much of the rigour of LCA as possible, i.e. to avoid unacceptable criteria (sometimes called "top-down" criteria) like "recycled", "recyclable", "natural", "without CFC", etc.

2.1 Matching concepts

There are obvious similarities between the first two steps of RA and the LCI and LCIA steps respectively.
In order to get to the risk management step, RA has indeed to perform a broad review of possible hazards where the life cycle concept has an important role to play as a support to ensure the breadth of the review.
Hence, hazards identification can usefully capitalise on a life cycle inventory.
The situation is less clear as to the degree of compatibility between LCIA and risk assessment. In particular, the former is far less explicit than the later in terms of actual &pacts. On a qualitative level however, knowing that a given substance is a potential source of impact on the ozone layer for example, is the first step of risk assessment in RA
Hence, risk assessment can usefully capitalise on a qualitative life cycle impact assessment.
In conclusion, we do not suggest that LCA concepts can match those of RA, but rather that LCA elements can prove useful as tools to partially implement RA's three steps (see Figure 1)

Risk Analysis as a Framework	Corresponding LCA elements as a tools
Identification	Inventory
Assessment	Impact assessment (qualitative)
Management	(void)

Figure 1 - Matching RA concepts and LCA elements as tools

2.2 Matching data

It would not be realistic to try and merge LCA and RA just by "plugging" matching concepts one into the other at a numerical level and still hope to meet our simplicity and cost effectiveness requirements.
We suggest however, that it can be done if data are exchanged at a qualitative level. Indeed, ***words*** are often the most effective medium to convey complex and subtle, possibly fuzzy pieces of information. This "wordy" approach was already taken, in slightly different ways though, by [10] and [11].
The framework developed on the basis of this merging of RA and LCA as previously defined is called INIES. It is presented in the following paragraph.

3 The INIES framework

INIES stands for "INformation on Impacts Environmental and Sanitary". It is a simple approach merging the LCA concept and elements with the RA framework. INIES makes use of any numerical and qualitative data available on products' EQ and sets them in a grids structure (step 1) designed to be readable and not to make assumptions that would impede on the management step of the RA framework. Then, a written summary of the grids content can be produced, to answer specific questions (step 2). Both steps are introduced below.

3.1 INIES step 1 – Fill in grids

INIES is a series of four or five grids – one for each life cycle step of a building product: raw material extraction (optional); manufacturing (production); setting up (construction site); service life (including maintenance); end of life (demolition site and disposal/recovery/reuse). The grid framework has been designed taking in account the building sector particularities. Grids are laid out as shown on Figure 2.

LC Step :							
Flows (1)		Environmental themes (2)					Recommendations (4)
		Resources preservation	Ecosystems preservation	Waste management	Health	Quality of life	
Energy			↑				
Materials	→	→	(3)				
Waste							

Figure 2 - INIES grids general layout

Lines of column (1) contain input and output flows nature and quantity, as provided by an inventory. A specific line is dedicated to waste (which in fact is a material flow) because it is a major concern for building products.

The five environmental themes result from a building products-oriented choice for putting together all the classical impact headings.

Potential effect of each flow on each environmental theme (2) is then mentioned in the corresponding cell (3), based on a qualitative impact assessment and any other source of information, including experts reports.

Column (4) is intended for recommendations on how to suppress, prevent, mitigate, etc. the risks mentioned on one or more themes. This column is particularly useful when existing regulations are either not satisfactorily addressing the issue or not applied in practice - wood burning on the construction site, for example.

Since almost any piece of information available on EQ can be reported in the cells and also because users of this information are mainly interested in the knowing the risk induced by a given hazard and how to manage it, INIES provides clear status indications for every piece of information. Possible status are :

Hazard identification : - Data not available – in that case no assessment will be reported
- Quantitative data
- Qualitative data

Risk assessment :
- Data not available, i.e. risk not assessed
- Not relevant as to present knowledge; i.e. no risk induced.
- Assessment without experts consensus
- Assessment with experts consensus

Management :
- No information on management
- Management according to existing regulations
- Advice on management in lack of relevant regulation

Reference regulatory texts pertaining to building products are few. There are however some general references which are applicable in that specific context. Among these, one can mention the European Waste Catalogue [12] and the European directive on products labelling [13].
INIES has been developed as part of a large project financed by the French ministries of Industry and Housing and the Ademe (French governmental agency of environment), in partnership with industrial associations, some general contractors and architects. This project was aimed at reviewing technical, economical and environmental aspects of a broad range of products issued from the steel, concrete, clay and wood industries. Within that project, which also served as a test bed for the INIES approach, participants agreed that INIES made possible a compilation and a clear presentation of EQ aspects and helped avoid misinformed or biased statements.
Since the target of this project was to produce EQ information on the largest spectrum possible, filling the grids was enough. But filled-in grids are not the final word of the INIES framework.

3.2 INIES step 2 – Synthesize information

To follow the recommendations for successful RA discussed previously, providing data is not sufficient. Information must be synthesised to provide a documented answer to the questions asked by a given actor.
Again, our experience is that words are an effective medium to communicate EQ information to various types of actors, and succeed where numbers failed.
This second step is currently tested in two ongoing projects.
Firstly, INIES is used as a basis for the introduction of EQ recommendations into an experimental revision of the French standards for wooden-framed houses construction – known as the DTU 3 1.2 [14]. This project is co-financed by Irabois and Ademe. The basic philosophy of a DTU (« Document technique Unifié ») is to act as a code of good design and setting practice for a given construction element. Hence in this context, a specific use for the data compiled into INIES grids is defined. We decided to fill the grids and then produce a short text summarising all risk management information and recommendations relative to the setting, service life and disposal steps of the product's life cycle. This resulting text will be inserted within the new experimental version of DTU 31.2.
The second ongoing project involving INIES is aiming at developing a procedure to include EQ criteria into the French product technical agreement delivered by CSTB. Again, grids are filled in for the product to assess and a short summarising text will be produced.

4 Conclusions and Future work

INIES is a building products' EQ documentation framework merging RA and LCA at a qualitative level. In a first step grids are filled with existing EQ information. Attention is paid to giving risk management recommendations or applicable regulations when available. In a second step a summarising text can be produced to address a specific question.
INIES can be used to :

- Inform and communicate on a building product EQ,
- Get informed on building products' EQ,

- Point to aspects not covered enough. As an example, most products lack guidance on maintenance and refurbishment. The absence of data will appear in the service life INIES grid and can push actors into asking manufacturers for more details,
- Suggest improvement tracks to manufacturers and possibly other actors,
- Push actors into defining and communicating on their environmental policies, because decisions taken on the basis of the information presented in an INIES grid set must explicitly indicate preferences and trade-offs between risks.

Details needing to be further elaborated include a closed list of statements denoting the grid cells' content in an unambiguous way. This list will be particularly useful in regulatory texts and technical agreement procedures.

The INIES framework is now close to being fully operational and its application to a broad range of generic building products is planned.

Saint-Martin d'Hères, France, december 1997.

References

1. NF EN IS0 14040 (1997) Environmental management – Life cycle assessment – Principles and framework, AFNor, Paris.
2. Merten, T. et al (1995) *Materialintensitätanalysen von Grund-, Werk- und Baustoffen (1)*, Wuppertal papers, No. 27, Wuppertal Institut, Nordrhein-Westfalen.
3. Udo de Haes, H.A. Editor (1996) *Towards a methodology for life cycle impact assessment*, Setac Europe, Brussels.
4. Le Téno, J.F. and Chevalier, J.L. (1996) A Tool for Improving the Environmental Quality of Building products. *Durability of Building Materials and Components 7*, Vol. 2, pp 839-847, E&F N Spon, London.
5. Finnveden, G. (1997) Valuation methods within LCA: where are the values ? International Journal of LCA, Vol. 2, No. 3, pp. 163-170
6. Le Téno, J.F (1997) How to produce useful results with LCA: the EQuity model for building products. *Second International Conference Buildings and the Environment*, June 1997, Paris, pp. 125-132.
7. Modarres, M. (1993) *What every engineer should know about reliability and risk analysis*, Dekker, New York.
8. Fischhoff, B. et al. (1981) Acceptable risk, Cambridge University Press, Cambridge.
9. Le Téno, J.F. and Chevalier, J.L. (1996) Life cycle analysis with ill-defined data and its application to building products. *International Journal of LCA*, Vol. 1, No. 2, pp. 90-96.
10. Boonstra, C. and Knapen, M. (1997) The handbook of sustainable building: a practical design tool. *Second International Conference Buildings and the Environment, June* 1997, Paris, pp. 157-l 64..
11. Storey, J.B (1997) Life-cycle environmental impact charts – a working tool for specifiers. *Second International Conference Buildings and the Environment*, June 1997, Paris, pp. 189-197.
12. « Catalogue Européen des Dechets »: a list established to apply the Directives 75/442/CEE and 91/1 56/CEE, and adopted through a decision of the Commission (20 déc. 1993).
13. Journal Officiel de la Communauté Européenne, No. L. 256 dated 16.10.93 and L. 13 dated 15.01.94, Annex I
14. DTU 3 1.2 (1993) Norme Française NF P 21-204-1, AFNor, Paris.

"Durability and Reliability, Alternative Approaches to Assessment of Component Performance Over Time"

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Abstract
This paper will describe some of the findings of the current UK Teaching Company Directorate funded collaborative research between consultants, Building Performance Group and the University of the West of England. The objective of the research is to provide a practical database on the durability of components and materials used in the construction industry. The current second stage of the research is focused on mechanical and electrical services systems and components in commercial buildings. The paper will compare the type of service life data available for commercial building services systems and components with building fabric components. The different types of data and failure pattern curves indicate that a different approach to maintenance management may introduce higher levels of reliability and sustainability in buildings.

The use of reliability engineering in the assessment of component service life is contrasted with the construction industry's current approach using durability. Techniques including reliability-centred maintenance and condition monitoring will be discussed in relation to the assessment of environmental, economic and life cycle performance. There will also be an analysis of one statistical method of modelling performance that can be used to optimise maintenance and renewal of building services systems and components.
Keywords : Building fabric, building services, durability, function, life-cycle, maintenance, sustainability, reliability, service life, statistical analysis, Weibull.

1 Introduction

In response to the increased need for data on the service life of building components, Building Performance Group (BPG) and the University of the West of England have been carrying out a four year research project sponsored by the UK Teaching Company initiative. The current research relates to mechanical and electrical (M&E) building services components in commercial and industrial buildings. The main objective of the research is to produce a unique database of building component service life data. The research has already contributed to the Housing Association Property Mutual (HAPM) "Component Life Manual" [1], and it is hoped that a similar component manual will be produced for M&E services components.

This paper examines the differences in the types of data, and failure distributions between fabric components and M&E services components in buildings. It is desirable to integrate the two types of data sets into a common format in order to facilitate the development of a single "cost in use" model for buildings. It seems that the construction industry has a definite need for the data in this format. The principle of reliability will be discussed in comparison to durability together with a review of the relevance of historical data. The findings indicate that a different approach to maintenance management based on reliability studies may promote more cost-effective and sustainable use of resources. Techniques including reliability-centred maintenance and condition monitoring will be discussed in relation to the life cycle, environmental, and economic performance over time. There will also be an analysis of the statistical models for service life prediction that can be used to optimise renewal of building services systems and components.

2 Different Approaches to Data Collection

The first phase of the research developed a broad methodology for the service life assessment of building components and has been adapted to building services :

- Identify potential existing sources of data on the durability of building services plant and equipment by reference to relevant organisations and published sources.
- Assemble a knowledge base of information on the durability and failure modes of selected building services plant and equipment.
- Extend the scope of the existing building component lifespan database to include data on a range of building services components and equipment for commercial buildings.

The assessment of building services life and failure compared with building fabric has highlighted some key differences. Due to the dynamic nature of M&E services components, failure may cause much greater disruption to the operation of business than fabric materials. For example, the failure of a boiler is far more of a problem than a cracked floor tile or peeling paint. On the other hand, concrete gets stronger over time, while bearings wear out. Failure and service life of M&E components are thus examined in terms of reliability rather than durability. Reliability engineering is a science in itself with component life generally measured more accurately in hours rather than years.

M&E services components can fail due to a wide range of failure modes. The commissioning process and warranty period should resolve many of the early stages of potential failure with M&E components. This represents the "burn-in" or "'infant mortality" stage of a failure distribution (see Figure 1). Failures occurring in the stages after this period are perhaps the most important from a service life point of view, especially when failures are often beyond warranty periods provided by manufacturers, and can lead to full-scale replacement rather than repair. The following describes what data and methodologies are available for failure management, and how this data can be used to ensure selection of reliable building services components. The technical failure history issue has attracted much discussion in the field of reliability engineering. Numerous paradoxes and shortcomings occur in relation to maintenance policy and historical life data :

(1) It has been suggested that if we are collecting failure data then it is because the failures are not being prevented ("The Resnikoff Conundrum") [2].
(2) Planned preventative maintenance (PPM) prevents the failures occurring for which we need data to optimise PPM.
(3) PPM often leads to failures occurring either due to human error or simply de-stabilizing and disruption of a sophisticated system.

"Burn-in" failures are in effect re-introduced each time "preventive" maintenance is carried out. Studies on the reliability of boiler plant [3] illustrated this fact in the concluding thoughts on the research : *"A disturbing outcome of the study has been the effects of servicing on plant reliability. The probability of plant failure increases considerably in the monthsfollowing a service visit?* In addition some of the worst industrial catastrophes in recent history have been caused by unnecessary maintenance intervention, eg. Piper Alpha and Bhopal [2]. Further discussion on the effects of maintenance policy on component lives is further discussed in section 6.

It is often thought that the ultimate aim in service life data collection is to gain real data from installations where the history is well known or has been modelled over a certain period of time. It is true that this may be the most useful situation but the discussed failure process issues must first be taken into consideration. Historical records do, however, have a major part to play and should be used to reduce routine maintenance to the minimum, and determine less disruptive maintenance programs.

The problem of deciding on the level of data collection required to manage maintenance and performance has been identified in other industries, and has led to a "paradigm flip" [4]. The old paradigm was to gather information in hope of improving performance, in terms of service life which may be equated to the study of durability. The new paradigm is to ask what information is needed to determine the possible performance, reduce the gap between current and possible performance, and maintain that new performance level. The research aims to provide an indication of what performance is possible with components through the study of their reliability. Where there are large numbers of identical components in a system and there is a cost consideration to failure, then the collection of real life data is practical. For components that follow an age related failure distribution and where costs of failure are high, then collection of real data is also feasible.

Various organisations are now introducing programmes of asset life cycle management which include an element of verification of performance and life data. In the petrochemical industry companies are combining smart sensor technology, neural networks, expert systems and computer technology to predict plant failure. These "systems" are based on those developed for aircraft maintenance and include computer software that provides data collection, intelligence to diagnose a problem, assess risk, and recommend action [5].

3 Reliability v. Durability : "In building and construction, reliability is often called durability" [6]

For the purpose or tne research, we have adopted the followmg definitions given in BS5760 :

- Durability is "the ability of an item to perform its required function under stated conditions of preventative or corrective maintenance until a limiting state is achieved".
- Reliability is defined as "the ability of an item to perform a required function under a stated period of time".

Manufacturers see reliability as having "a vital effect upon the life-cycle efficiency, profits and market share" [6]. Economic asset management has long recognised the importance of quality and performance indicators to assess whole life performance. A particular item of building services plant or equipment, like a building, will certainly be produced to fit into a particular band of quality. The reliability of equipment is measured in relation to a product quality definition supplied by the manufacturer. It is thus possible to refer to 'good' and 'bad' reliability targets and maintainability figures. This form of asset performance profile modelling allows the establishment of a reliability confidence range or benchmark [5]. Reliability then relates to success or failure in service or use and is attained if the quality provided by the producer is adequate. Manufacturers of mechanical and electrical components investigate their product's reliability, and even demonstrate expected failure rates. They recognise the need to supply data in order to allow the assessment of confidence for life cycle cost estimates. Manufacturer supplied data is available for M & E building components in relation to failure and reliability. The level of information provided in relation to reliability and maintenance data is increasing due to increased competition, complexity of installation, and guarantee packages provided. There is still, however some scepticism in the construction industry in providing service lives. A number of reliability data banks have been set up to provide indications of expected failure rates, which include M&E building components [7], but not building fabric components. In the UK the HAPM Component Life Manual is still unique in giving "insured lives" for building fabric components, and some M&E components.

The information on component failures may be expressed as Mean Time Between Failure (MTBF), Failure Modes, and Failure Mode and Effect Analysis (FMEA). The MTBF is defined as the average life of a particular component [6] which is statistically different from expected service or useful life of a component. The use of MTBF in particular situations is, however not to be relied upon as the sole basis for maintenance decision making, and does not indicate the required frequency of maintenance tasks. It can be used in calculating desired availability, frequency of failure-finding testing, and whether planned maintenance is worth doing, but not how often. It is accepted however that in many cases reliability and maintenance data will not be available. This refers to actual real time to failure which can enable verification of estimated data in relation to the life cycle of M&E building components. This data can also be used to calculate optimum replacement strategies from components using statistical modelling techniques as discussed later.

Durability has long been studied in relation to the performance of fabric building components, but the above definition of durability highlights the absence of the “period of time” aspect. Reliability concentrates on this factor and is used in an engineering context when looking at the service life of M&E services components, and also is :

- Qualitative, as it examines freedom from operational failure in service or use on a comparative scale.
- Quantitative, as it is concerned with the probability that an item will operate in a prescribed fashion for a prescribed period of time under prescribed conditions without suffering any event predefined as a failure.

4 Failure Distribution Patterns

Traditionally the “bath-tub” distribution is used to model component failure. This has been called “the folklore of reliability engineering” [8], and other failure distributions have been identified in other industries, which are of relevance to building components. The following Figure **1** [2] illustrates most of the failure distributions that might be found in a building and its associated components :

A: “Bath-tub curve” with high incidence of failure *(infant mortality* or *burn-in*) followed by random or gradually increasing failure rate, then by a wear-out zone.
B: Random or slowly increasing failure probability, ending in a wear-out zone.
C: Slowly increasing probability of failure, but there is no identifiable wear-out stage.
D: Low failure probability when the item is new or just out of the shop, then a rapid increase to a constant level.
E: Random probability of failure at all ages
F: High infant mortality, which drops eventually to a random or very lowly increasing failure probability.

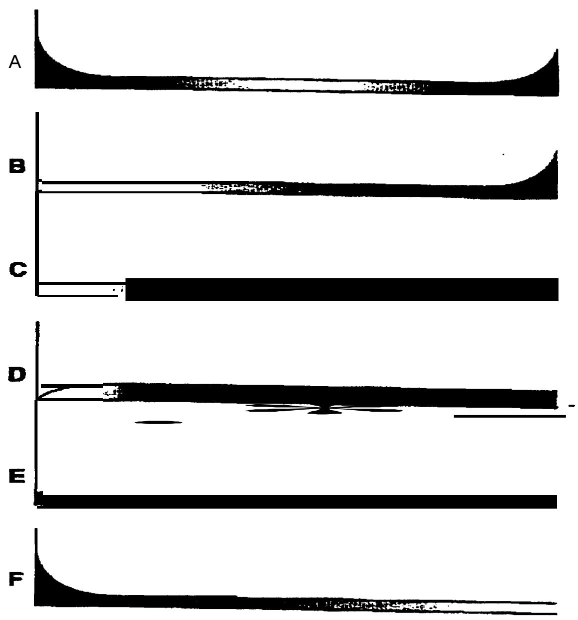


Figure 1 - Failure Patterns [2]

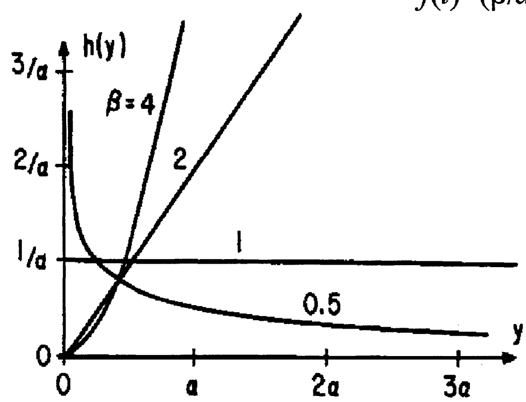
The basis of any maintenance policy or accurate life-cycle analysis is the understanding of the failure characteristics of individual components. Studies in the Civil Aviation Industry [2] have showed that 4% of items conform to pattern A, 2% to B, 5% to C, **7%** to **D, 14%** to E, and **68%** to pattern F. As M&E services components grow more complex, patterns E & F are likely to become more common. These findings suggest that there is not always a link between operating age and reliability and hint at the paradoxes with failure data discussed in Section 2.

5 Statistical distribution and the Weibull function

Several statistical functions can be used to model the failure rates and distributions discussed above including log normal, Gaussian, gamma, and Weibull [10]. The Weibull distribution is suitable for use in this context, and is widely used and preferred as it *"has a great variety of shapes which enable it to fit many kinds of data, especially relating to product life"* [2]. Predicting future trends or patterns associated with a common failure mode affecting a specific component is an essential part of maintenance planning for mechanical and electrical services. A predictive technique must estimate the time at which the failure rate is deemed unacceptable, not simply the time to first failure, which may itself be difficult to anticipate. As a starting point this may involve an assumption that all failures will simply continue at their current rate or perhaps incorporate some element of "educated guess" for a moderate increase.

Predictions of component failures can be made with greater confidence by using the Weibull Distribution Function which is seen as a powerful and versatile statistical tool for the analysis of reliability life data and hazard probabilities. It is uniquely able to model situations irrespective of whether the failures represent part of an increasing, decreasing, or constant exposure to failure mechanisms. Figure 2 below illustrates the 'hazard function' which highlights the variety of shapes which can be attributed to the full range of failure patterns shown previously in Figure **1.** The data required in order to carry out a Weibull analysis is the time-to-failure of the components being studied. Statistically the Weibull frequency distribution (or probability density function) is :

$$f(t)=(\beta/a^{\beta})t^{\beta-1}\exp[-(t/a)^{\beta}]$$



W eibull hazard functions.

Figure 2 - [Source :10]

The Weibull Beta value achieved from the above equation dictates the shape of the curve [10] and where :

Beta < 1 - burn-in failure is occurring, which equates to pattern F [Figure 1]
Beta = **1 -** random failure is occurring, which equates to pattern E
Beta > 1 - wear out failure is occurring, which equates to pattern B

6 New Approaches to Maintenance Management

It is widely acknowledged that once a failure distribution is known or modelled, a suitable maintenance policy can be determined [10]. Recognition of the maintenance policies available have changed much since the early 1980's. Possible failure management policy options available today to improve life cycle performance include:

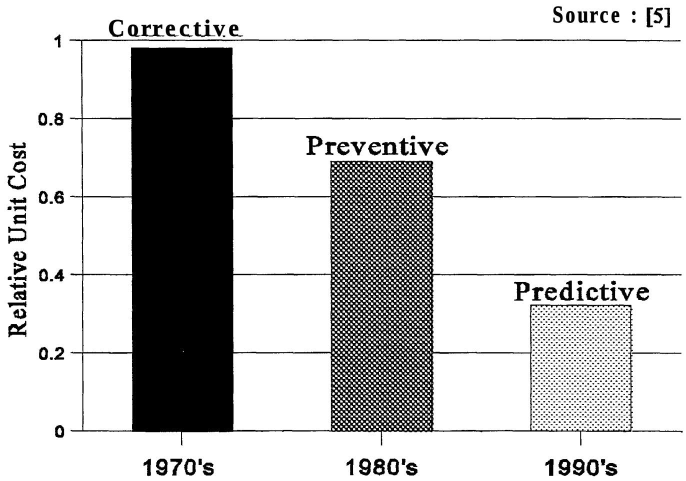
(1) Predictive maintenance
(2) Preventive maintenance
(3) Condition-based maintenance
(4) Failure finding
(5) Change the design or configuration of the system
(6) Change the way the system is operated
(7) Just-in-time maintenance
(8) Run-to-failure

Processes are available to help identify a suitable failure management policy for dealing with each failure mode in the light of its consequences and technical characteristics. One such process is "Reliability Centred Maintenance " (RCM) which finds its roots in the American Civil Aviation industry in the early 1960's, and is used world wide especially in the process, aviation, and defence industries. The RCM process importantly first defines what users want in terms of function (safety, environmental and sustainable integrity, reliability, durability), and then quality (precision, accuracy, consistency and stability), control, comfort, containment, economy, customer service etc. The next step is to identify ways in which the system can fail to live up to these expectations (failed states), followed by an FMEA (failure mode and effects analysis), in order to identify all the events which are reasonably likely to cause each failed state [2]. This allows the selection of the most suitable building maintenance strategy and has been successfully used in a number of major commercial buildings. Recent technological developments in condition monitoring equipment and that can be used to detect failure before it occurs have led to greater emphasis on policies such as predictive, condition-based and just-in-time maintenance. Building services components often have a detectable or measurable progression to failure and are therefore suitable for such techniques. For example the mechanical failure of bearings in a centrifugal pump would be characterised, over regular time intervals, by :

(1) vibration,
(2) noise,
(3) heat,
(4) smoke and possibly fire.

The process industry has done much work in assessing the effect of different maintenance policies in order to lower the life cycle costs of components [5], as illustrated in Figure 3 :

Figure 3 **Maintenance Costs - Process Industry**



7 Conclusion

Policies for the life cycle analysis and maintenance management of mechanical and electrical building services components are being heavily influenced by new technologies from other sections of industry. The actuarial approach to data collection is often less useful than statistical analysis in predicting component failure used in deciding maintenance management policy options. Failure patterns can vary extensively and do not necessarily fit the "bath-tub" distribution. Data on failure rates is certainly available for M&E building components from manufacturers and data banks that can assist in making correct maintenance decisions, but this data is not readily available for building fabric components. It has been shown that incorrect planned maintenance strategies can actually increase life cycle costs, and reduce reliability and service life.

Differences in the data format and the data collection process for fabric and M&E components are evident, and the use of the Weibull function has been suggested as one example method for data analysis. Reliability theory may be used as a single methodology to assess building component performance of both mechanical and electrical services and fabric components. This would allow the development of a common cost-in-use model for life cycle analysis. In order to use such a model effectively, there is still a definite need for data giving actual time-to-failure or replacement in order to verify and explain existing service life predictions for building components in general, and allow more cost effective predictive maintenance.

8 Acknowledgments

1. The UK Teaching Company Directorate (Department of Trade and Industry).
2. Building Performance Group Ltd.
3. Faculty of the Built Environment, University of the West of England, Bristol.

9 References

1. HAPM (1992) *Component Life Manual,* E.& F.N. Spon, London.
2. Moubray, J. (1996) *RCM II - Reliability-centred maintenance,* Butterworth-Heinemann, Oxford.
3. BSRIA (1980), *TN 1/80 - Reliability of Boiler Plant,* Butler, H & Petts, C.
4. Lamb,G.R. (1997) *HP In Competitiveness,* Hydrocarbon Processing, August 1997.
5. Honeywell (1997) *Equipment Health Management,* Honeywell Loveland, USA.
6. British Standards Institute (1994) *BS* 5760 - *Reliability of systems, equipment and components,* BSI, London.
7. Smith, D. J. (1992) *Reliability, Maintainability and Risk,* B&H, London.
8. Shooman, M.L. (1968) *Probabilistic Reliability : An Engineering Approach.* McGraw-Hill, New York.
9. Nelson, W. (1980) *Applied Life Data Analysis,* J. Wiley & Sons., USA.
10. Grover, R. J. & Grover, *C. S.* (1984) *Life Cycle Costing and Reliability Theory,* Proc. 3rd Symposium on Building Economics, CIB Working Commission W-55, Ottawa, July 1984, pp 29-37. Vol 1.

Material flows in the construction and heavy engineering sector

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Abstract
About 90 per cent of all natural stone, sand and gravel in the construction and heavy engineering sector is re-used. Asphalt is 60 per cent re-used and wood is about 80 per cent converted into energy. Concrete waste, on the other hand, is only 20 per cent re-used. These figures come from a study prepared by AB Jacobson & Widmark for the Swedish National Environmental Protection Agency.

In an average year, 6 million tonnes of waste are released by the alteration and demolition of roads, installations and buildings. Of this, 43 per cent is reused, 7 per cent is recycled, 5 per cent is incinerated for energy-production and 45 per cent is dumped or landfilled.

There are different types of landfills, e.g. for building or demolition waste clean fill, etc. often in old gravel pits. Concrete, brick, stone and lightweight concrete are usually counted as approved infill, though lightweight concrete is not approved in the presence of water, because it floats. Plaster is allowed in small concentrations. Metals, plastic and wood usually occur, due to the difficulty of completely separating out these materials.

Three-quarters of the material released consists of asphalt, concrete, sand and gravel. Other materials, then, constitute a minor proportion. Metallic waste has a high recycling rate, about 70 per cent. About 35 per cent of glass waste is recycled. Plastic, board, paint, mineral wool, textiles, ceramics, concrete, jointing compounds, lightweight concrete and screed at present are to a very great extent (80-100%) dumped or used as infill.

The total quantity of material incorporated in buildings, roads and installations is estimated at 2,500 million tonnes (two billion five hundred million tonnes). The estimated quantities include all materials in buildings, roads and other structures in Sweden. Exceptions have been made, for example, for spillage during maintenance and construction, military installations, outdoor and underground utilities, equipment belonging to installations and scaffolding.

The survey of material flows provides an overview of present-day conditions. It conveys an idea of the magnitude of the material flows, how they differ between the categories of in-built quantities, quantities released in connection with building and alterations and quantities released by demolition and alterations. The survey also yields information as to how these quantities of building material released are dealt with.
Keywords: Building materials, dump, energy-production, material flow, recycle, re-use,

1 Priority principle

In its work on producer liability, the Swedish Government's Ecocycle Commission has given priority to building materials. For these it has indicated the following priority principle:

- *Resource conservation,* i.e. testing when the material needs to be demolished and giving priority to measures reducing the amount of residual products.
- *Re-use of products,* e.g. re-using roof tiles fi-om a demolished house as roof tiles on another house. *Recycling of materials ,* as for example when metal is melted down and becomes new metal.
- *Recovery ofenergy,* e.g. incineration of wood waste.
- *Landfill.*

The Ecocycle Committee for the Building Sector, in its "Action plan for environmental responsibility for building materials, a wider producer liability", has, through its enterprises and organisations, pledged itself among other things:

- to identify hazardous waste from building, maintenance, alteration and demolition and to pre-separate the waste so that it can be dealt with in an environmentally appropriate way,
- to pre-separate residual products not later than 1997, partly in order to improve the prospects for recycling industry,
- to halve tipping quantities from the building sector not later than 2000.

The term "building sector" refers to all members of the construction industry. All of us, then, are jointly and severally bound to honour the above pledges. Dependable figures used to be lacking concerning the amounts of material incorporated in all the buildings and heavy constructions of Sweden. Nor was there any overview of data concerning the amount incorporated in connection with building, alteration and enlargement. Lack of knowledge has obstructed the greening of the building sector.

J&W were therefore commissioned by the Swedish Environmental Protection Agency to chart the flow of materials. Material quantities have been calculated by quantifying system-built houses, roads and installations and by processing existing statistics of the number of buildings, total length of roads and volume of other structures.

2 Purpose of the survey

The purpose of this extensive survey was to compile supportive data for the Agency's continuing work on the ecocycling of building materials. The following building materials and sub-groups were included: concrete, lightweight concrete, asphalt, stone, sand and gravel, brick and ceramic materials, metal, plastic, wood, roofing felt, glass, plasterboard, insulation materials, jointing compounds, screeds, asbestos cement, linoleum, paint and textiles.

3 Results and conclusions

3.1 Results

*Table 1. Total quantities for buildings, roads and structures, by groups of materials. For cut-of points, normal year and errors, see Swedish **Enviromental** Protection Agency Report no. **4659**(in Swedish).*

Total for buildings, roads and other structures					**Breakdown of quantities released**				
Material	***In-built***	***New production***	***Rebuilding and renovation***	***Quantities released***	***Tipping***	***Landfill***	***Energy extraction***	***Material recycling***	***Reuse***
	k-tons	*k-tons/yr*	*k-tons/yr*	*k-tons/yr*	*%*	*%*	*%*	*%*	*%*
Concrete	552,000	7,600	1,060	1,090	5	75		20	<1
Plaster board	9,600	116	41	31	95			<5	<2
Mineral wool	5,600	83	44	17	99			1	
Plastic	1,300	16	11	6,9	60-80	5-10	20-25	<1	
Joint'g compound	115	0.4	2.2	2.7	80		20		
Glass	2,200	19	13	14	65			<1	35
Wood	68,600	301	232	360	15 I	<5	75-85		l-5
Metal	23,400	230	245	180	20-50			60-80	
Brick/ceramics	155,100	219	79	290	5	75		10-20	<5
Stone	81,000	11	67	470		10			90
Sand & gravel	1,280,000	24,340	30.500	540		10			90
Lightweight concrete	28,900	187	157	88	30	60	20	10	
Roofing felt	515	9	3	2	75	5			
Screed	16,200	27	58	50	5	75		20	
Asbestos cement	1,800	0	0	40	100				
Linoleum	250	6	1	3	85		15		
Paint	760	5.3	9	7	60		20	20	
Textiles	96	5	3	2	85		15		
Asphalt	262,000	3,560	4,100	2,700		40			60
Total	***2,500,000***	***37,000***	***37,000***	***6,000***	***5***	***40***	***5***	***7***	***43***

*Landfill = **building** tips, spoil heaps, **infill,** e.g. of old gravel pits, with uncontaminated spoil. Tipping = reuse tip. **The** correct values for in-built and turned over quantities respectively should come with in the interval between 0.8 and 0.6 times the stated value minus, respectively, 1.2 and 1.4 times the value stated.*

Table **1** Handling of the quantities released by demolition and alterations.

The results of the survey warrant several interesting conclusions, for example:

- Sand and gravel, concrete and asphalt account for the overwhelming proportion by weight of the total quantities, namely **84** per cent in-built and **72** per cent released.
- Released quantities sent for tipping and landfill total 45 per cent altogether, 58 per cent for building and **36** per cent for roads and civil engineering works.

Much work remains to be done in order to compile more accurate statistics on material flows. Subjects for further study are suggested in the report.

The survey provides valuable information on the way in which the quantities of building materials released are dealt with. Management varies a great deal from one group of materials to another:

- Materials extensively re-used are stone, sand and gravel (about 90%) and asphalt (60%).
- 80 per cent of wooden materials are used for energy-recovery .
- Recycling of window glass is at present confined to re-use of windows (35%). Recycling of flat glass is minimal at present, partly because the company for recycling of glass in Sweden (Svensk Glasatervinning) now concentrates on consumer products. It is estimated that less than 1 per cent of flat glass from the building sector is sent for recycling.
- The proportion of metals sent for recycling varies between 60 and 85 per cent, depending on metal prices.
- A very large proportion of the other materials ends up in various dump sites or landfills (SO-100%).

In the accompanying table, results have been compiled concerning amounts released for buildings, roads and civil engineering works during an average year in the course of an economic cycle (= normal year). According to the survey, a total of 6 million tonnes are released annually, of which 45 per cent are being sent to a dump site or a landfill, 5 per cent for energy recovery, 7 per cent for material recycling and 43 per cent for re-use. These figures for the handling of quantities released refer to 1996.

The same table summarises results concerning in-built quantities up to and including 1995. According to the survey, 2,500 million tonnes of materials are built into houses, roads and installations. Sand/stone, concrete and asphalt account for the overwhelming proportion (84%) of total quantities.

3.1 Estimated uncertainty of the calculated data

Inaccuracy is due to the uncertainty of the statistics regarding the number of buildings, roads and installations and of the method of quantified system-built houses, roads and installations.

The uncertainty regarding the number of houses in existence is estimated at ±10 per cent. In addition to numerical calculations from Statistics Sweden valuation units, results from statistical sample surveys of the house population, conducted at the Institute for Building Research in Gävle, have also been used in selecting the number of buildings.

The uncertainty of the quantification of materials in system-built houses has been estimated at ±10 per cent. For individual types of material occurring in small quantities, e.g. jointing compound containing PCB, the error may be greater.

In the case of roads and installations, it proved unexpectedly complicated to find relevant figures for in-built quantities or quantities added to or disappearing from the system, the reason being that the available statistics do not normally include material quantities: often they give investment and maintenance costs only.

In the report, uncertainty is estimated at ±20% for in-built quantities and ±40% for turned over quantities (new production, alterations and renovations and quantities released). This means that the right values for in-built and turned over quantities respectively should come within the interval between 0.8 and 0.6 times the stated value to respectively 1.2 and 1.4 times the stated value.

3. 2 Delimitations

The quantities include all materials in buildings, roads and other installations in Sweden, with the following exceptions:

- maintenance of buildings,
- waste in connection with maintenance, new building and the national Housing Improvement programme (ROT),
- military installations,
- water and sewerage mains,
- power and telecommunications lines outdoors or in the ground,
- local soil in connection with road and railway construction,
- water heating and sanitation pipes below ground, light pressed brick, rendering, putty and glue,
- equipment in harbours, at airports etc.,
- pre-standing wardrobes, white goods, furniture, textiles other than permanent carpeting,
- scaffolding, shuttering and telephone/electricity poles.

3.3 Examples of material quantities:

An account is given below of quantities and of the disposal of released quantities for a number of building materials selected from the report.

3.3.1 Jointing compounds

Hazardous waste is not always disposed of in the prescribed manner, due often to ignorance of where the materials are and which materials are classified as hazardous waste under the Chemical Products Act. One relevant problem here is the PCB-containing jointing compounds which were used in buildings, above all during the 1950s and 1960s.

The figures concerning residual jointing compounds presented in other reports are of the order of 100-500 tonnes of PCB (Hammar, 1992). In another study, Boije and Markensten (1993) state that 70490 tonnes of PCB have been used for jointing compounds. Certain compounds included PCB in concentrations of 10-50 per cent. According to Öberg, 1994, the amount of PCB in double-glazed panels could be estimated at about 170 tonnes originally and the residual quantity at SO-100 tonnes. Given a PCB content of 25 per cent, this corresponds to a glued joint quantity of 200-400 tonnes.

In this survey of jointing compounds in prefabricated façades and in double-glazed panels from the period when PCB could occur, we estimate that there are about 5,000 tonnes ofjointing compound containing PCB. According to our calculations, 2.2 tonnes of jointing compound containing PCB are released every year as a result of demolition and modernisation.

The total quantity of jointing compounds, according to the above mentioned investigations, comes in the interval between 1,000 and 5,000 tonnes of jointing compound containing PCB. Our figure touches the upper limit.

In a recent report to the Swedish Environmental Protection Agency, researchers at Stockholm University advocated clearance of these joints, the reason being that they were able, from measurements in soil, to show that seepage and spread are considerable. Removing and replacing the joints would probably cost about MSEK 2,000.

Öberg estimates the amount of PCB in remaining Acrydur floors at 20-30 tonnes. The proportion of PCB in a complete Acrydur floor from 1950-60 (certain types of Acrydur flooring only) is about 12 per cent. The remaining flooring compounds containing PCB would then come to about 150-250 tonnes.

3.3.2 **Asbestos cement**

After 1976, asbestos cement was not used in new production except under certain exemptions granted up until 1982. Production of asbestos cement in Sweden began in 1920. Imports during the 1970s were running at 20,000 tonnes per annum up to and including 1976. The survey shows 1.8 million tonnes of asbestos cement to be in-built and 40,000 tonnes to be released by demolition and rebuilding every year.

3.3.3 Concrete

Over 550 million tonnes of concrete are in-built and 8.7 million tonnes are added annually. Just over a million tonnes of concrete are released annually as a result of demolition and alterations, and most of this (75%) is turned into landfill.

Cementa have kindly supplied material showing total cement consumption in Sweden and the market sectors in which cement is sold. Up until 1996, according to these statistics, cement sales in Sweden totalled 142 million tonnes. Ninety per cent of the cement manufactured in Sweden was used for manufacturing concrete. The remaining 10 per cent is used for mortar, tunnel grouting, deep stabilisation etc.

Sweden in 1996 produced about 2,2 million tonnes of concrete elements annually. Deliveries of concrete from the members of the Swedish Ready Mixed Concrete Association to on-site casters amount to some 6 million tonnes. About 5 per cent is delivered by non-members. Buildings dating from between 198 1 and 1990 contain almost 80 per cent concrete.

In many municipalities, a large proportion of concrete etc. is used for road building at refuse disposable plants. In Luleå and Helsingborg, nearly all concrete is crushed for recycling. In other municipalities, remaining, un-recycled concrete is deposited on landfill sites, some of which are municipally owned while others are private. It is not possible to distinguish the quantities deposited at municipal and privately owned landfill sites respectively. Conditions differ a great deal between regions, with certain municipalities also receiving and recording waste sent for landfill, while others have no dealings with landfill at all.

3.3.4 Plasterboard

At present 9.6 million tonnes of plasterboard are in-built and 0.2 million tonnes are added every year as a result of new production, alterations and maintenance. Plasterboard has been manufactured in Sweden by Gyproc, which between 1958 and 1994 produced 7 million tonnes. There have also been some imports of Danish and Norwegian plasterboard, accounting at present for some 30 per cent of the total use in

Sweden.

Plaster recycling takes place in Bålsta and will soon be starting up in Åhus. Soil improvement is a new application for plaster, and this is expected to increase in the next few years, plaster having proved to have a very beneficial effect on soil and crops. If use for soil improvement gets under way as expected, probably at least 50 per cent of plaster residues from new buildings and demolition can be recycled before 2000. At present 95 per cent is dumped.

Plaster is approved in most regions as filler if it is mixed with "mineral" material. It is not possible to distinguish the quantities dumped on municipal and private landfill sites respectively. Conditions differ a great deal between regions, with certain municipalities also receiving and recording waste sent for landfill, while others have no dealings with landfill at all.

3.3.5 Mineral wool

About 5.6 million tonnes of mineral wool were sold in Sweden between 1958 and 1994. This is the same quantity as the present authors estimate to be in-built. Every year, 127,000 tonnes of mineral wool are added and 3 1,000 tonnes released. At present Rockwool, Gullfiber and Roxull sell about 120,000 tonnes of mineral wool per annum.

Recycling in the form of loose wool insulation will increase over the next few years. Gullfiber and Rockwool have signed contracts with loose wool contractors all over the country. The target is 50 per cent recycling in 2000 (including recycling of waste from new buildings). It is estimated that recycling can already reach about 10 per cent (of the mineral wool released by demolition) in one year's time.

3.3.6 Lightweight concrete

Deliveries of reinforced and unreinforced lightweight concrete from Siporex, Durox and Ytong between 1958 and 1995 give 27.7 billion m^3, while production pre-1958 amounts to 4.2 million m^3 for Ytong and similar quantities for Siporex and Durox. Given an average volumetric weight of 0.6, the total quantity manufactured comes to 24 million tonnes. Our calculation in this survey gave 28.8 million tonnes. New production and renovation, according to the present survey, given 128,000 tonnes per annum, whereas Ytong produces only 60,000 tonnes annually. Here we have probably overestimated the amount of lightweight concrete turned over every year in the building of new single-family dwellings and alterations to industrial facilities. In many municipalities, lightweight concrete is used together with concrete etc. for road building at the refuse dump site (estimate 10% approx.). Lightweight concrete which is not recycled is deposited on landfill sites.

3.4 The first attempt

This is the first attempt at charting the material flows of the building sector in Sweden. The figures are subject to a great deal of uncertainty, due to the shortcomings of the statistics, but the material still conveys a good picture of quantities and composition. The comparisons we have made for control purposes show that several of the figures used previously may be incorrect or highly inaccurate. For example, the figure of 2.5 tonnes of plastic per dwelling unit frequently figures in the literature. It emanates from all national plastic output divided between dwelling units and does not refer solely to the plastic present in building materials, structures and installations.

3.5 Further studies needed

The report describes the need for further studies:

- Better statistics concerning the number of buildings are needed, with a view to more reliable calculations. Within the near future, the buildings register of the National Land Survey will probably afford a sound basis for statistics of this kind.
- Quantification of some additional materials not included in the present survey, e.g. heating, water and sewerage pipes below ground, light pressed brick, putty and rendering.
- Further comparisons of the results of this survey with other available statistics and analysis of any differences between them.
- Inclusion of spillage from new production and maintenance of buildings in the material quantities.
- Statistical field studies are a viable way of obtaining a good, accurate picture of the flow of building materials.
- Construction of a database for material flows.
- Lucid presentation of material flows.
- Quantities in new building and civil engineering projects, through a number of studies of different typical projects.

4 References

AB Jacobson & Widmark, Kartlaggning av materialfloden inom bygg och anlaggningssektorn, Naturvardsverket rapport nr 4659, *Swedish Enviromental Protection Agency Report no. 4659(in Swedish).* 1996.

Boije, Louise, and Markensten, Hampus. Miljonprogrammets giftiga baksida, PCB i fogmassor i flerfamiljs elementhus 1956-l 972. Degree assignment, spring 1993, University of Linkoping. Tema vatten i natur och samhälle.

Hammar, Tommy, PCB i fogmassor, Lansstyrelsen i Kalmar län informerar 1993 :20.

PCB i fogmassor - stort eller litet problem? Rapport 4697, 1997. Naturvardsverket.

Öberg, Thomas, Förekomst av PCB och PCN i varor och kemiska produkter i Sverige. Kemikalieinspektionen PM nr 1 8/94.3.

The life cycle simulation method EQUER applied to building components

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Abstract

Sustainability objectives influence the development of products by adding supplementary quality criteria. Some of these criteria can be evaluated by quantitative indicators, according to the life cycle assessment (LCA) method. An evaluation tool, based on numerical simulation of buildings life cycle, is presented in this article with an application example.

This life cycle simulation code (EQUER) is linked to a thermal simulation tool (COMFIE) and to a data base including many processes (fabrication, transport, energy transformation, waste management, etc.). Renewal and recycling of products is taken into account. The results (e.g. GWP, acidification potential) are presented in the form of spider charts. Technical solutions can be compared in order to evaluate the benefit of innovative techniques in relation to a reference, and to improve products. The interest of this process is to consider the whole life cycle of components and to account for possible interaction with the rest of the envelope, the site, and the occupants' behaviour.

The methodology is illustrated by an example of transparent insulation. A cellular polycarbonate structure is studied and characteristics needed for thermal analysis are determined. The inventories for glass, aluminium, wood and polycarbonate are used for a first evaluation of the fabrication impact of the component. Interaction between the component and other parts of the envelope is taken into account : the radiation collected through the component is stored in a masonry ; comfort requirement and maintenance issues lead to have also opaque insulation in the wall, with a corresponding impact. The environmental benefit of the transparent insulation component, in relation to a reference wall, depends on the location of the building, the occupancy pattern (dwelling or office building,...) and the characteristics of the envelope (thermal inertia, solar aperture). The distinction between generic characteristics and specific performance is discussed. Sensitivity studies can support product development, e.g. reducing the thickness of material lowers fabrication impact but increases heating energy consumption, and these effects can be balanced using LCA.

Keywords : life cycle assessment, simulation, building materials, environmental impacts

1 Introduction

The emerging sustainable construction practices raise many questions concerning technical choices, and particularly the characterization and selection of building components. Various tools are proposed like guides, lists or labels but the underlying criteria and hypotheses are often not transparent. Comparing materials or presenting the environmental benefit of techniques requires explicit criteria and verifiable assessment.

The environmental benefit of a technique (e.g. the reduction of CO2 emissions obtained by an insulation material) is related to a reference (e.g. a typical wall with or without insulation). This reference should be representative and correspond to a standard in terms of construction techniques. But such a standard is related to a specific location. Also, in the previous example the amount of CO2 emissions depends on the climatic conditions, the-use of the building in which the wall could be included, etc. Comparing alternatives might provide different results for different locations and buildings. Tools ranking materials on a general basis are thus hardly credible, and the aim of the work presented here is to study how technical alternatives can be compared and on which level -component or whole building- the various properties and performances should be assessed.

2 Principle of the life cycle simulation

Assuming that the environmental performance of building components may not be generic and may vary according to the location, building use etc. implies to assess the environmental performance of whole buildings and to rank alternatives using sensitivity studies. If all sensitivity studies, in every climate and every case give the same results, the ranking is then general and the assessment can be regarded as a generic performance of components : it depends on the component itself and not on the location or the building.

Previous studies have shown that the environmental performance of a building is the result of several factors like integration in a site and urban design, architectural design, technical choices and occupants behaviour. Environmental assessment methods should account for these various interacting aspects in order to provide a relevant help to decision makers.

Environmental quality criteria can be very broad, including comfort and aesthetical aspects. We limit the present study to quantifiable aspects. Also, comfort issues have been the subject of many previous studies, and we are focussing here on environmental impacts which is a more recent concern.

Life cycle assessment (LCA) seems to be the least criticable method at the moment to assess the environmental impacts of products [1,2], and we have chosen this approach. But the specificity of the building sector has to be taken into account. In many cases, a building is unique and its design cost is limited. LCA must then be automatized to reach this productivity constraint. We developed a computer tool, which makes comparison of alternatives easier.

Because this model has already been described in previous publications [3,4], we only give here a summary presentation. The functional unit considered is a building located in a certain site and occupied for a certain use (e.g. dwelling, offices,...), with an appropriate level of comfort and quality in general. The system boundary is defined according to the needs of each study and may not be limited to the building. For instance if the purpose is to compare various building sites for the same project, transportation issues may be taken into account. Processes like electricity production, domestic waste treatment, transportation of building materials are taken into account, so that the system is broader than the building itself. Energy consumption for heating has a major contribution in the global balance, and our LCA tool has been connected to a thermal simulation tool (COMFIE, [5]).

The model comprises entities (or classes) corresponding to technical objects of the building (materials, components,...), to processes (transportation, energy use, water utilisation, waste management,...), to the site (selective sorting, collective transportation,...) and to environmental indicators (inventories, energy and water flow meters,...).

A complete description of the corresponding data structure has been established using the formalisms defined in the STEP-Standard, NIAM (cf fig. 1) and EXPRESS [6].

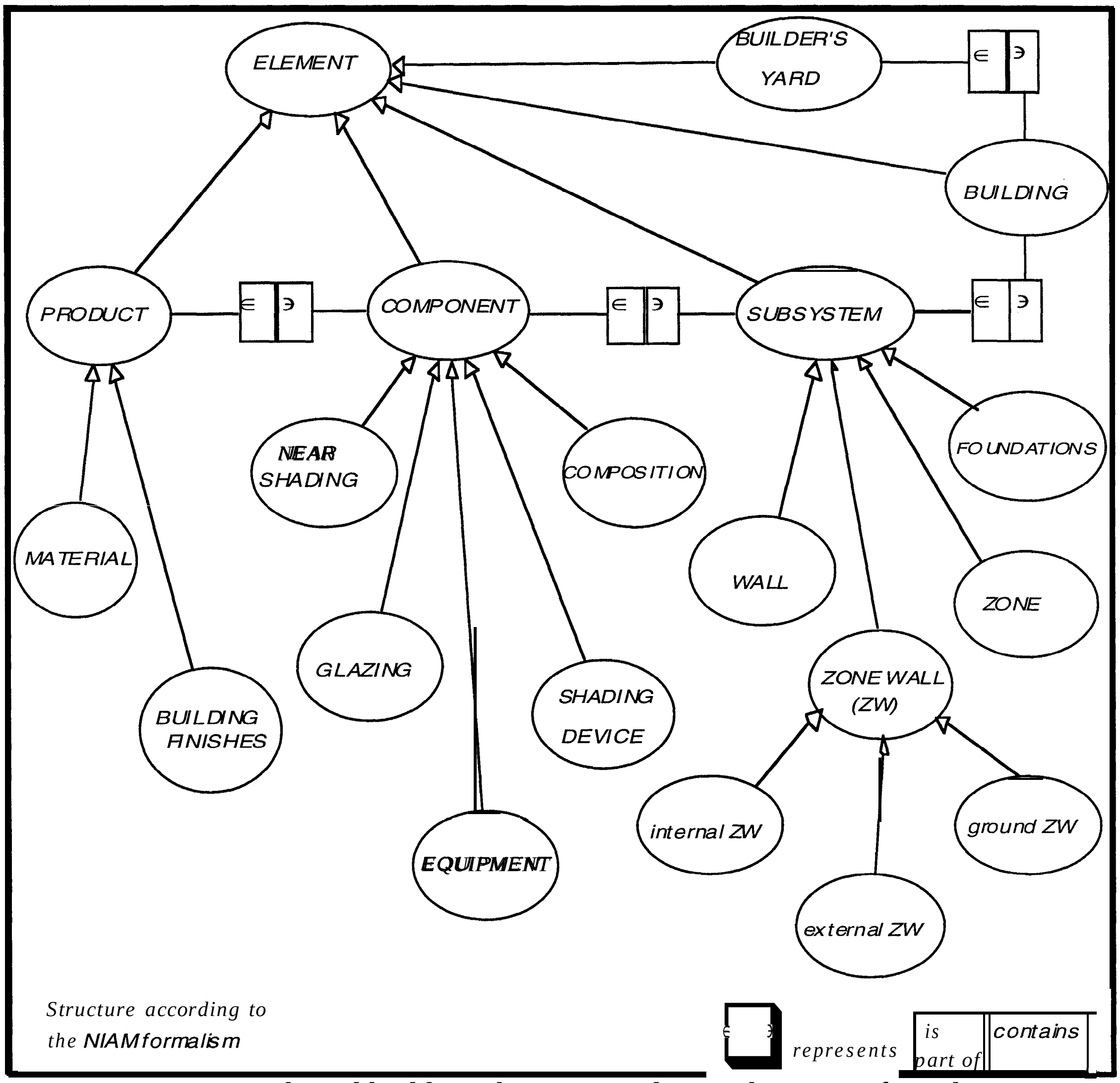

Figure 1 : Technical building objects according to the NIAM formalism

The different phases considered for a building life cycle are:

- the fabrication of components
- the construction
- the utilisation
- the renovation and the renewal of components
- the final dismantling

- the treatment after use of components (the possible reuse and recycling of components is taken into account).

The environmental impact of building components or processes (e.g. energy use, transport) can be evaluated on the basis of inventories. An inventory is a table of elementary fluxes, indicating the quantity of each emitted or used substance with regard to the unit of the component or process. The used inventories, collected in the Oekoinventare or similar data bases [7,8], contain the following categories of elementary fluxes :

- the used resources (e.g. rare materials, primary energy, water)
- the emissions into air, water, ground (e.g. CO_2 into air, ammonia into water, oil into ground)
- the created waste (e.g. inert, toxic, radioactive).

These inventories, in the form of excel files, have been used here thanks to the REGENER project [9]. The excel files are transformed into an access file (data processor). This allows to derive C++ objects and to evaluate component inventories by combining materials and processes (e.g. 1 m^2 of window is obtained by adding 20 kg of wood and 13 kg of glass). This data processor also transforms the inventories into impacts (characterization step) in order to simplify the data before transmitting it to the simulation tool. The CML indicators are considered [9].

The overall impacts of a building system, occurring during its life cycle, are calculated by the tool by a one year time step simulation (cf fig. 2) and constitute the ecoprofile of the building.

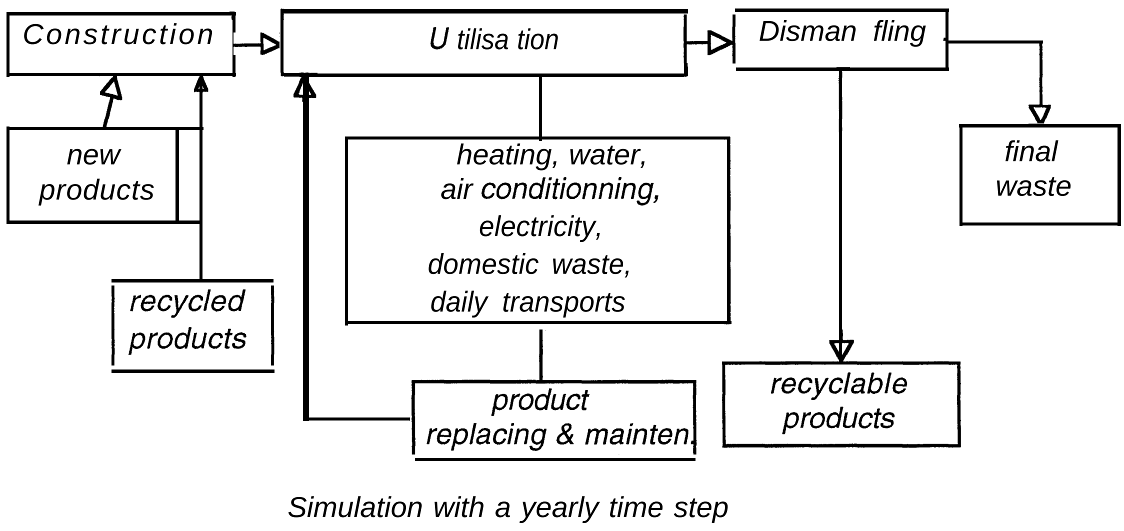

Figure 2: Principle for calculating the overall inventory of a building

This ecoprofile includes 12 environmental themes :

- resources used (abiotic resources, primary energy, water),
- planetary effects (global warming potential)
- regional effects (acidification, eutrophication, smog, human and eco-toxicity, odours)
- waste produced (radioactive or other).

These indicators are represented using a web diagram, in which either the different phases of the life cycle or alternative designs can be simultaneously shown.

3 Example application to transparent insulation

The tool desbribed above can be used for various purposes, e.g. comparing different building sites, occupants' behaviours, architectural designs.. . We illustrate here a possible use concerning the comparison of building components. The objective is to evaluate the environmental interest of two transparent insulation techniques.

3.1. Description of the system

Transparent insulation materials (TIM) have been proposed in order to collect solar gains on opaque walls [10]. A polycarbonate capillary structure, encapsulated between two glass panes, has been integrated in Trombe walls according to fig. 3.

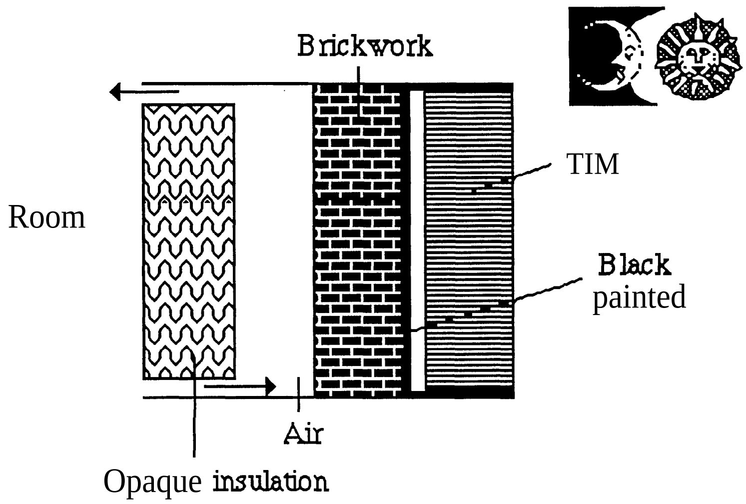

Fig. 3 : schematic principle of a Trombe wall with transparent insulation

A part τ of the incident solar radiation is transmitted through the transparent insulation layer, partly absorbed on the black painted surface of the wall and the heat is transmitted to the brickwork This heat is stored in the masonry (11 cm thick) and transmitted to an air flow, and thus towards the dwelling, with a time delay. In summer or during cold and overcast days, the air flow can be stopped thanks to movable louvers. When the louvers are closed, the opaque insulation layer (10 cm of glasswool) reduces the undesired heat flux. A movable shading device is thus not necessary, which avoids maintenance problems. An alternative has been compared, in which the TIM is replaced by a cheaper polycarbonate plate.

3.2 Generic performance of the components

The physical properties of the components, which are needed for the thermal analysis and eventually for LCA, are the transmission factor and the heat loss factor of the whole transparent insulation layer (polycarbonate structure and glass panes). The transmission factor in terms of the direction of incident radiation has been measured using a " megasphere " [11].

Table 1 : physical values for the two transparent covers considered

material	mean heat loss factor $W.m^{-2}.K^{-1}$	transmission of solar radiation (diffuse-hemispherical)
10 cm encapsulated capillary structure	0.8	0.67
16 mm polycarbonate plate	2.4	0.64

3.2 Productivity of the components

Using these characteristics, we performed in parallel a thermal simulation and measurements on monitored houses [12]. The measured heating load in the two single family houses with TIM are 3,560 kWh and 7,037 kWh. In the first case, the occupants had stopped the mechanical ventilation, and the mean temperature in the house was 16,3°C, compared to 18,8°C in the second house.

Simulation was used to predict the heating load with the same ventilation pattern, a mean temperature of 19°C, the same internal gains and a typical year. The result is 7,000 kWh. This allowed comparison of various systems, a similar analysis giving 7,700 kWh for the houses with the polycarbonate plates. The houses concerned here include 11 m^2 of Trombe walls.

In order to evaluate the productivity of the component, we defined a reference : the same wooden frame house, replacing the Trombe wall by the wall constituting the other facades, i.e. a wooden wall with 10 cm glasswool insulation. With the same climatic data and occupancy pattern, the heating load of the reference house is 8,360 kWh. The energy saving obtained by the Trombe walls with TIM is approximately 1,360 kWh (approx. 120 kWh/m^2) and half this figure using polycarbonate plates.

This productivity varies in terms of the area of component, particularly in the case of wooden frame houses because of their low thermal inertia. This illustrates the interaction between the different parts of building envelopes. Thus, the productivity cannot be presented as a generic characteristic of one particular component.

3.3 Comparative life cycle assessment

Compared to the reference, the passive houses (with a Trombe wall) have a larger impact during the contruction phase because of the supplementary component and a lower impact during the utilisation phase thanks to energy gains. This can be balanced using LCA. The inventory of the TIM (resp. polycarbonate) component has been estimated by combining wood, aluminium, glass and polycarbonate inventories (resp. wood and polycarbonate).

The system limits have been adapted to the objective of this study, focussing on the comparison of two components (with electric heating) : transportation of persons from home to work, management of domestic waste, water consumption have not been considered. A 3,150 kWh yearly electricity consumption for electric appliances and lighting has been accounted for. The life time considered in the analysis is 80 years. The results are the following (fig. 4) for the reference house and the houses with a Trombe wall.

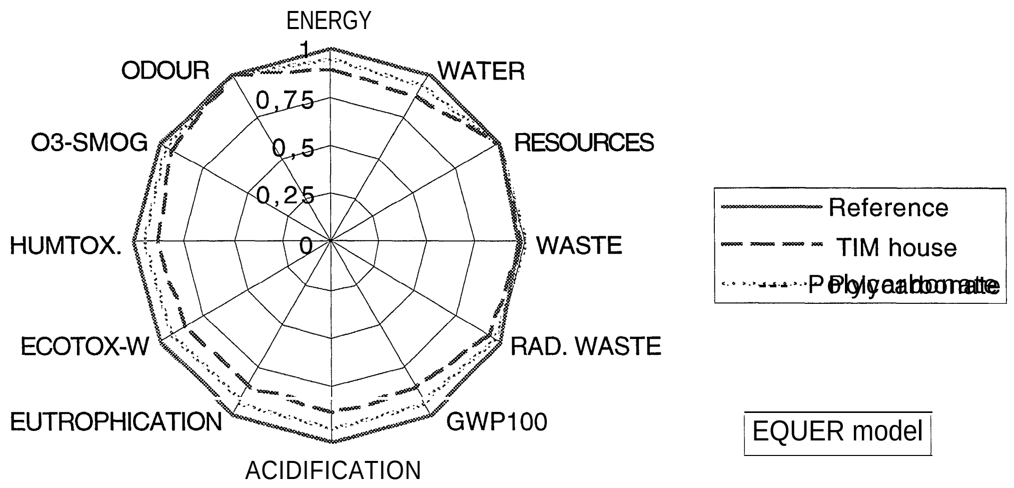

Fig. 4 Comparative ecoprofiles of two different components and a reference

The Trombe wall with a TIM cover leads to a 16% reduction of heating load and 10% reduction of the GWP of the house (about 77 tons of CO_2, or 7 t/m^2). The reduction of GWP related to the utilization phase (78 tons) is much higher than the increase during construction and renovation (about one ton). The performance of the house with a simpler polycarbonate cover is between the reference and the TIM house.

4 Discussion

For components influencing the thermal balance of buildings, life cycle assessment shows the importance of energy related aspects concerning most environmental impacts. But other aspects like depletion of resources could become more important in the future. The characterization of components should concern only generic performance indicators, e.g. physical properties, fabrication or disposal inventories. Performances like the reduction of CO2 emissions depend on the site, the use of the building and the rest of the envelope. It seems thus difficult to provide designers with environmental assessment of components which could be used in every building projects.

Life cycle assessment does not address all issues, and particularly human or eco-toxicity aspects are difficult to assess because the location of the emissions is not considered in LCA. Risk assessment methods would be more appropriate concerning these topics, but require a more detailed modelling of air and mass transfer in buildings.

5 Conclusions

A life cycle simulation tool has been developed and linked to a data base on building materials. This tool has been applied for various projects and studies, concerning different actors (architects, clients,...) and phases (urban and building design, management,...). The example given here concerns a comparative assessment of transparent insulation materials. This example shows that energy related impacts play a large role in the case of components influencing the thermal balance. Environmental performance of components (e.g. the reduction of CO2 emissions compared to a reference) is not generic and depends on building location, on the reference chosen, the use of the building etc. so that characterization of components should rather concern physical properties or fabrication/disposal inventories.

Because energy related aspects are essential in the global balance, energy saving or solar technologies should be considered when studying improvement of the environmental performance of buildings.

Acknowledgements

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References

1. SETAC (Society of Environmental Toxicology and Chemistry), A Technical Framework for Life Cycle Assessment, *Smugglers Notch Workshop Report,* Washington DC, USA, (1991)
2. ISO, International standard n°14040, final draft, Environmental management -life cycle assessment- principles and framework, 1997
3. B. Peuportier, B. Polster and I. Blanc Sommereux, Development of an object oriented model for the assessment of the environmental quality of buildings, First International Conference "Buildings and the environment", CIB, Watford, may 1994
4. Bernd Polster, Bruno Peuportier, Isabelle Blanc Sommereux, Pierre Diaz Pedregal, Christophe Gobin and Eric Durand, Evaluation of the environmental quality of buildings - a step towards a more environmentally conscious design, Solar Energy vol. *57* n°3, pp 219-230, 1996
5. Bernd Polster , Contribution à l'étude de l'impact environnemental des batiments par analyse du cycle de vie, these de doctorat, Ecole des Mines de Paris, 1995,268 p.
6. B.Peuportier and I. Blanc-Sommereux, Simulation tool with its expert interface for the thermal design of multizone buildings, *Int. Journal of Solar Energy, 8* (1990)
7. IS0 10303-21, Standard for The Exchange of Product model data, (1994)
8. R. Frischknecht et al., Ökoinventare fiir Energiesysteme, ENET, Bern (1994)
9. W. Baumgartner and N. Kohler, Energie- und Stofffluß- bilanzen von Gebäuden während ihrer Lebensdauer, EPFL-LESO, Lausanne, Switzerland, (1994)
10. Bruno Peuportier, Niklaus Kohler and Chiel Boonstra, European project REGENER, life cycle analysis of buildings, 2nd International Conference " Buildings and the environment ", Paris, june 1997, pp 33-40.
11. R. Heijungs, Environmental life cycle assessment of products, Centre of environmental science (CML), Leiden, 1992, 96p
12. A. Goetzberger, Special issue on transparent insulation, Solar Energy vol. 49 number 5, 1992
13. S. Soler, M. Gery and J.L. Chevalier, Theoretical and experimental study of the behaviour of multi-wall ribbed materials under solar radiation, Transparent Insulation Workshop TI 6, Birmingham, 1993
14. Bruno Peuportier and Jacques Michel, Comparative analysis of active and passive solar heating systems with transparent insulation, Solar Energy vol. 54 n°1, jan. 1995

The interrelationship between performance and service life of building products

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Abstract
The paper discusses the interrelationship between the performance of building materials and components and their service lifes. The paper suggests to take advantage of the methods and tools developed in working with the performance approach in building for assessing what sort of data is needed, how much information is desirable and what are the minimum requirements. A proposal for a systematic procedure is given. The paper discusses the problems connected with whether testing should be performed on materials or components level, the difficulties of "translating" results from materials to components or from degradation indicators to performance properties.
Keywords: Performance concept, performance data, durability data, service life.

1 Introduction

When we are dealing with the question of predicting service life or assessing long term durability, it is always a prerequisite that the building and its parts has a satisfactory performance. It is without interest to discuss service life or durability if it is not first ensured that the building will function properly under its intended in-use conditions. Performance and service life are therefore closely related and it is impossible to talk in depth about the one without mentioning the other. Service life may then be defined as the time during which at least the essential performance properties are maintained at a satisfactory level.

1.1 The performance approach in building - CIB W60

For quite some years international cooperation on "The performance approach in building" has taken place in CIB comrnision W60. The work has mainly focused on the performance of building materials and components. A number of publications have been issued by the commision including CIB report 64 "Working with the Performance Approach" [1].
The publication gives the basis for a methodology to be used in listing performance properties and criteria for building materials and components.

1.2 Prediction of Service Life - CIB W80

Similarly international cooperation regarding prediction of service life has taken place in the joint CIB W80/RILEM committee working with "Prediction of Service Life". The first result published by the committee is now a RILEM recommendation on Techniques for Service Life Prediction [2]. This recommendation is a methodology for how service life can be predicted using different paths.

1.3 The purpose of this paper

This paper should be seen as an attempt to:

* account for the relationship between the performance of materials and components and the service life
* account for the performance data that are necessary in service life prediction
* give guidance on how and where performance data may be found.

Hopefully this wil make it possible to focus investigations more on achieving results on properties related to the requirements of the user and the authorities. The manufacturers should thereby be better suited to design and use the results of durability tests and the material specifiers better suited to select the best solution.

2 The interrelationship between performance of materials and components and durability

The trend towards the use of the performance approach and performance specifications in building arises from higher expectations of the conditions to be provided by the building, from the availability of improved space planning and design techniques and from the accelerating rate of change of building techniques. The performance concept is a particularly valuable tool especially when new innovative solutions are proposed and consequently the behaviour in use is unknown.

2.1 The interest of the end user

For the end user the major interest in a building he owns or occupies is that it functions properly in accordance with his requirements - and that it continues to do so for a long time. How the performance is achieved is not a matter of concern. The user might not even be interested in what type of roof covering is used or whether a comfortable in-door climate in winter is achieved via insulation or via a good heating system.

Performance of entire buildings is very complex and a lot of the performance requirements of whole buildings are more or less independent of building materials and components e.g. type and size of rooms. On the other hand, in an actual building the proper functioning of materials and components have at least indirectly a big impact on the performance of the entire building, e.g. the proper functioning of the thermal insulation material ensures a comfortable temperature in winter and the roof covering ensures that water is not entering the building. Therefore it is important that materials, components or other building products have properties that ensure the overall performance of the entire building. For the user, one important "property" of all building products is their ability to maintain their performance over at least a specified time.

2.2 Performance over time

To maintain the overall performance of the building each one in the set of building products that constitute the building shall possess certain properties on a sufficient level. This means that some properties, e.g. for a material or component, are critical and can only decrease to a certain level without affecting the overall performance of the building. For example, the watertightness of a roof covering shall remain unchanged over the entire service life. Other properties of the material on the other hand might well decrease without affecting the performance of the building. For example, change in the colour of the same roof covering might not necessarily be considered a problem.

2.3 Common parts of the methodologies

The two CIB committees have each developed a methodology for how to deal with the performance concept and service life prediction respectively, as shown in figure **1** and 2 respectively. In the latter figure the first step is problem definition which includes specification of the user needs, identification of the building context and, identification of the performance requirements. This is inspired by and consequently is very similar to what was done in the work of the CIB committee W60: "Working with the performance approach in building".

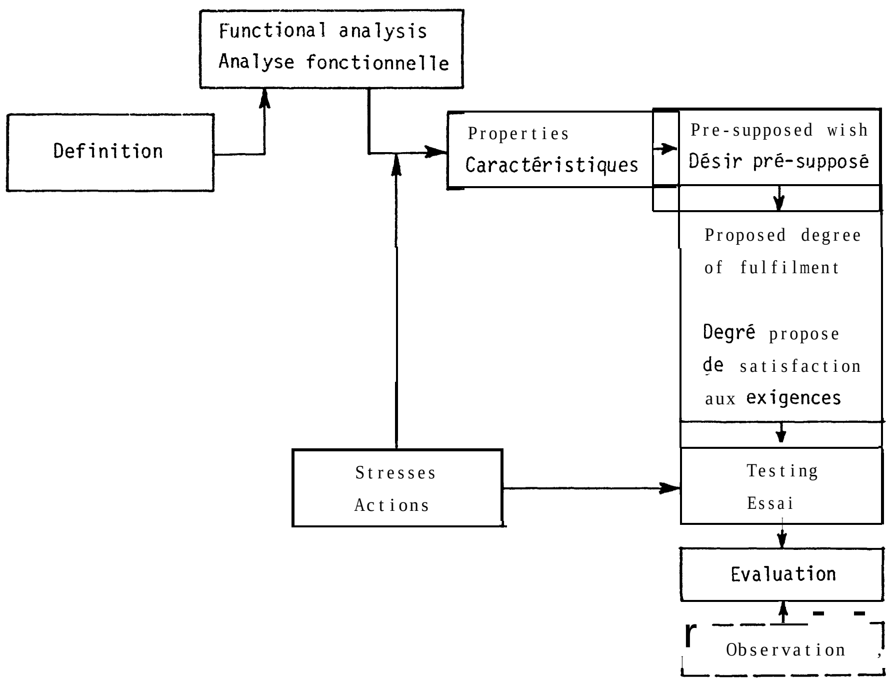

Figure 1. The methodology for working with the performance concept.

It is suggested to take more advantage of the tools developed by CIB W 60 when working with service life prediction thereby making the evaluation of test results performed by the two different methodologies more consistent and more valuable to the user.

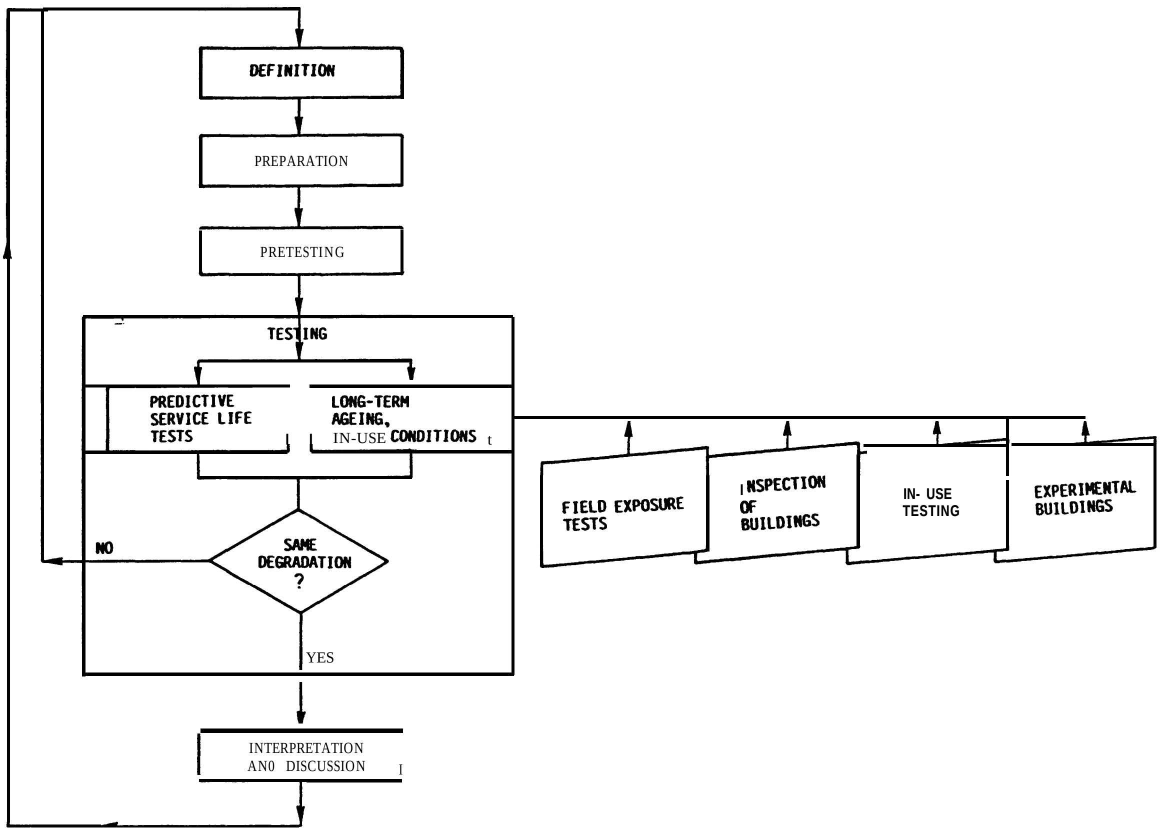

Figure 2. The service life prediction methodology.

3 How are performance properties identified and assessed?

The performance concept has been in use for quite a long time now, and it has found widespread use e.g. in building codes, for specification and as the basis for development of test methods and standards. The methodology ensures that the work is done in a systematic way so nothing is overlooked. This means reducing the risk of being deceived by new products with some apparent and convincing assets but lacking other less obvious, but important, properties which might prove to be fatal to the performance or the service life. The parameters of greatest importance for achieving and maintaining the performance will be determined and we are dealing with those parameters only, whereby it is ensured that time and money are not wasted.

In order to find the performance properties of a building product it is common to carry out an analysis where the functions of the product and the influence from the use are found. On basis of this the properties are determined. The results of the analysis are a natural basis for the design of the necessary performance test methods which are, as far as possible, simulations of the stresses on the product in use. Evaluation is based on whether the functions are maintained under the influence of the antipated stresses from the use. For products meant for general use the influence from the use should be determined as the factors and on the levels most unfavourable to the product, e.g. if a window is intended for general use in a variety of countries the one with the highest level of wind driven rain should be decisive for the requirements to that specific agent.

The requirements must be specified in conjunction with the test methods and should reflect for instance the ability to withstand external load, demands for comfort by the end user and requirements to health and safety as set up by the authorities. The user requirements are independent on the location in which the object is used, whereas the requirements from the authorities and the influence from the environment might vary depending on the location. This procedure is described in detail by CIB W60 in CIB-publication **64** [1].

4 Performance data and ageing tests

The information gathered in finding the performance properties and requirements of a product can be used again in the design of ageing tests. The agents and stresses that were found to be acting on the material or the component during the use and which were of importance for the performance, include the stresses of importance to the service life. The knowledge of these stresses must be combined with information about the actual materials and/or components in order to assess the possible degradation factors of the actual product in the intended use.

In order to limit the number of possible ageing tests it is an important issue to assess which of the performance properties are most critical and which are most vulnerable to the possible degradation factors. The result of this assessment is a decision about which performance properties are going to be used as decisive for the service life. At the same time the stresses/degradation factors that are anticipated to be important are revealed.

When designing an accelerated ageing test it is important to keep in mind, that the service life of a material or component is under the presumption that the use is “normal”. Service life for products which are abused e.g. exposed to greater load, more UV-light or vandalism is impossible to predict.

4.1 Key performance properties

Property	Stress
Air tightness	Wind pressure
Tightness against driving rain	Driving rain
Geometric compatibility	
Ease of opening	Passage of person in case of fire; general use; attempted burglary
Reliability in use	Mechanical movements

Figure 3. List of key properties for a “normal size” wooden window. "Normal size is defined as less than 1500 mm in width or height. The window is with double-glazed panes and are primarily intended for housing not exceeding three storeys.

CIB's Master Lists [4] may be of great help for an analysis of building materials and components and so may information about exposure environment, e.g. IS0 6241. The intention is to set up an exhaustive list of 15 - 20 properties for a component - possibly somewhat fewer for a material - based on every imaginable function of the product and every imaginable stress from the use including the degradation agents from the exposure environment.

Ideally, all performance properties mentioned shall be maintained at a satisfactory level for the prescribed life time. In practice this is, however, very difficult and expensive to achieve. A more pragmatic solution is to work on a more simple basis and look at the most important properties - key properties - for the product. For windows ths more simple basis could for instance be "normal size" wooden windows. For these an evaluation of the properties could result in a reduced list of properties, e.g. as described in Figure 3.

4.2 Performance over time

When working with the performance approach requirements of the product are marked on so-called banded levels, i.e., open ended scales designated with the letters (J), K, L, M, N, 0, (P). The further to the right the property is on the scale the "better" it is. This should, however, be compared to how much is really needed - the "necessary" should be strived at. For example, there is no reason for requiring a window which is airtight to high wind loads if it is intended for use in one-family houses on protected locations. Or, in other words, there is no reason for paying extra for a quality which is not needed. An example of the scales is shown in figure 4. Also shown is an example of how a performance profile is used for characterization of the product and how the profiles can be used for comparisons between a possible solution and the requirement as set up by the specifier, see Figure 5.

K L M N 0

Air pressure 200 300 500 700 Pa

Figure 4. Example on banded level for airtightness of a window (expressed as the pressure at which a certain amount of air passes the window per hour).

It is suggested to take advantage of this approach when dealing with assessment of durability. For the key performance properties the minimum acceptable levels are marked on the scales, and one should never go below these minimum values. In ageing tests the key properties should be tested at intervals to give an indication of how the minimum values are approached. For the properties that turn out to approach most rapidly an assessment or a mathematical model of the service life might be made. Even if this is not possible, the results of the repeated tests might give basis for a qualified assessment of the durability. For the wooden window, for instance air and watertightness might be tested every now and then.

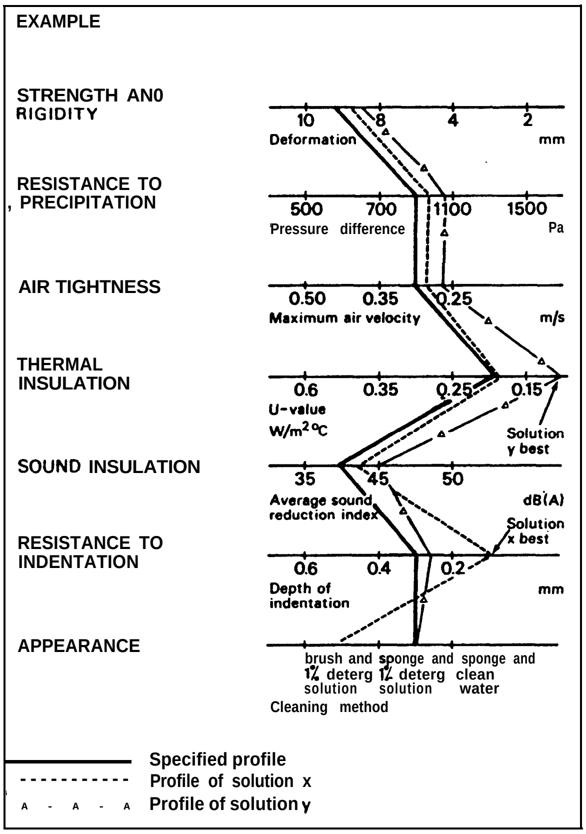

Figure 5. Comparison of performance profiles

5 From test results to performance

When performing ageing tests it is always a question whether tests should be on a material, component or even building level. Normally, testing on a material level is easiest because test specimens are small, the number of specimens can consequently be increased which is an advantage to statistical treatment of results. Besides, it is easy to maintain, for instance a uniform UV-exposure on small surfaces. The difficulties appear when test results on a material level is "translated" into performance of, for example, a component. For a wooden window - as an example - the performance should be put together by the results from the paint (or maybe paint on a wooden substrate), the hinges, the wooden joints, the weather strip etc. Each of these materials has been evaluated on basis of one or more relevant degradation indicators and it is obvious that it is hard to use the results to give any clear statements about the window. On the other hand, materials test are excellent to compare different paints on wood, different weatherstrips etc.

Testing on component level is normally restricted to few specimens due to the size which restricts the statistical use of the results. Due to the size of the test equipment the possibilities of accelerated tesing may be limited. On the other hand the testing takes compatibility and design into account and when it comes to "translation" of test results the difficulties only refer to the uncertainty of the acceleration.

6 Conclusion

Very little exploration on the subject of this paper and especially on the problem of coming from test results to performance has taken place and much needs to be done. Any contribution to a discussion including any possible information on performance descriptions for materials and components, descriptions on how results from ageing test are used in practice etc. will be very much appreciated.

7 References

1. *Working with the Performance Approach in Building*, (1982), CIB report 64, International Council for Building Research Studies and Documentation, CIB, Rotterdam.

2. Masters, L.W. and Brandt, E. **(1989)** Systematic Methodology for Service Life Prediction of Building Materials and Components, *Matériaux et Constructions/Materials and Structures.*

3. *CIB Master Lists*, (1972), CIB report No. 18, CIB, Rotterdam.

4. *General List of Performance Requirements* (in Danish. An informal translation into English is available in limited numbers), (1974), Danish Building Research Institute, Hørsholm.

5. Masters, L.W. (ed) (1986), *Prediction of Service Life of Building Materials and Components,* CIB Publication 96, International Council for Building Research Studies and Documentation, (CIB), Rotterdam.

6. Masters L.W. and Brandt E. (1987), Prediction of service life of building materials and components, *Matériaux et Construction&Materials and Structures.*

Release and flows of metals from building materials due to corrosion and degradation

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Abstract
Runoff measurements of heavy metals from different material surfaces used in buildings and other materials were conducted to identify potential sources of heavy metal emissions due to corrosion and degradation. The runoff was collected from different metal containing materials during two runoff periods with a total duration between one to two weeks. Elevated concentrations were found for zinc in runoff from galvanized steel, aluzink and paint containing zinc compounds, for lead from PVC surfaces and red lead based painted surfaces, for chromium from new concrete tiles and chemically passivated aluzink surfaces, for nickel from asphalt roofing felt and older concrete tiles and for copper from older concrete tiles. This study was performed on relatively small samples, with a single orientation and during short exposure periods and further research is needed to establish realistic runoff rates from materials exposed on buildings and other constructions during longer exposure periods and with different orientations and inclination of the surfaces.
Keywords: Heavy metals, runoff, corrosion, degradation, building materials.

1 Introduction

Metals are important components in the modern society and are used in large amounts in buildings, in constructions and in vehicles. In the ongoing accumulation of metals in urban environments an increased risk of detrimental effects due to emissions of heavy metals to the environment can be suspected in the long-term perspective. Metals runoff from materials on buildings and other constructions can give a significant contribution to metal emissions in urban enviroments. In recent studies [1] the aqueous emissions of metals such as zinc, cadmium and lead have to a large extent been attributed to emissions from diffuse sources, to which corrosion and degradation of materials containing metals belong. Although the rates of corrosion and degradation of different materials have been studied extensively investigations of runoff from metals are rare. However, realistic values of metal emission rates are essential in order to estimate the contributions from different materials and products to the total flow of metals to the environment.

Metals are used in a wide range of materials and components used in buildings and other constructions and many of these materials are exposed to environments where they can be subjected to corrosion and degradation, for instance roofs and facings, poles and barriers, plumbing installations and motor vehicles. Examples of building materials which are composed of metals or contain significant amounts of metals are shown in Table 1. **As** shown in this table a wide range of materials are possible sources of metals emission when they are subjected to corrosive environments. Metal coatings and metallic materials are obvious candidates, but other materials such as paints, plastics and concrete which are used in large amounts on buildings and constructions may also be potentially important sources of metal emissions.

In a research programme initiated by the Swedish Environmental Protection Agency [2] the flow of different metals from buildings, constructions, vehicles and other products to the environment is evaluated for the greater Stockholm urban environment. As a part of this programme, investigations of metal emissions and runoff rates of different materials are conducted, in the first place to identify materials which significantly contribute to emissions of heavy metals, and secondly to determine realistic values of metal emissions from common building materials. This paper presents results of a study of metal emission from a wide range of these materials containing metals in order to provide a basis for further investigations of metal emission rates from important materials.

2 Experimental

2.1 Performance of field exposures

The samples were exposed at a test site close to the Swedish Corrosion Institute which is located at the outskirt of central Stockholm. There are no local sources of metal emission close to the exposure site except a road with dense traffic approximately 100 m from the exposure site.

The metal samples, the coil coated samples, the asphalt roofing felt and the concrete samples were exposed from the end of April until the middle of May and the PVC samples and the painted samples in September 1997. The materials were exposed 19 days in total, but runoff from the first rain events was not collected. Runoff from three samples of each material was sampled during two periods, each about one week long. The samples were mounted on polycarbonate holders and the runoff was collected quantitively from the samples in containers of the same material. The surfaces were oriented with 45° inclination facing south except for the concrete surfaces which were exposed at 60°.

Table 1. Important applications of materials containing heavy metals in buildings and other constructions

Metal	Materials	Applications	Chemical form
Zinc	rolled zinc sheets, galvanized steel	roofs, faces, gutters, barriers, poles, pipes	zinc
	paints (pigments)	barriers, poles	zinc, zinc phosphate
		roofs , faces, windows	zinc oxide
	brass	plumbing, fittings	zinc
	rubber	tyres	zinc oxide
Cadmium	polymers (stabilizers,pigments),	PVC gutters	cadmium compounds
	glass	traffic signals	"
	coated steel	fasteners	cadmium
Lead	lead pipes	plumbing installations	lead
	fittings	"	lead
	PVC pipes (stabilizers)	"	lead stearate, ...
	anti rust paint	steel constructions	lead oxide
Chromium	stainless steel	roofs, faces	chromium
	concrete	constructions, roofs	Cr^{3+}-,Cr^{6+}-compounds
	surface protection of metals	steel constructions, fasteners, roofs	"
	paints	roofs, facings	"
	wood impregnation	buildings, constructions	"
Nickel	stainless steel	roofs, faces	nickel
	asphalt tar felt	roofs	nickel compounds
Copper	rolled copper sheet	roofs, faces, gutters,	copper
	brass	plumbing, fittings	copper
	wood impregnation	buildings, constructions	Cu^{2+}-compounds

2.2 Materials

The materials used in the field study were chosen from common building materials used on roofs, facings and other components in buildings and other constructions. Most of the materials used were new but a few samples have been exposed to atmospheric environments before the start of the runoff experiments. The following materials were exposed in the investigation:

- Galvanized steel (new)
- Aluzink steel with a coating of 55% Al, 43% Zn, 1.8% Si (new)

- Coil-coated steel, PVC-plastisol coating (new)
- Stainless steel (new)
- Asphalt roofing felt, coated with gravel (new)
- Concrete tiles, pigmented with iron oxide (both new and old)
- PVC gutter (old)
- red lead paintcoated steel (new)
- linseed oil based paint on steel containing zinc oxide (new)
- alkyd paint, anticorrosive paint containing zinc phosphate (new)
- Polyethylene, new, applied as inert surface (new)

The Aluzink is protected with a passivating solution which creates a thin layer containing chromium on the surface; the coil-coated material is chromium rinsed and has a chromium containing primer and a PVC plastisol topcoat which does not contain any heavy metals. The lead content of the PVC gutter was analysed with atomic absorption spectroscopy after dissolving the material. The sample contained 0.6 weight % lead, originating probably from heat stabilizers added to the material during manufacture.

2.3 Analysis of runoff

After collection, the runoff water was acidified with HNO_3 corresponding to 1 ml acid in 100 ml solution and stored in polyethylene bottles. The analysis of the runoff was performed with ICP-AES or ICP-MS (plasma emission spectrometry or plasma mass spectrometry) for all surfaces except the runoff from painted materials and the PVC material which were analysed by atomic absorption spectrometry.

3 Results and Discussion

Concentrations in runoff from different materials are presented in Figures 1 to 8. The concentrations of metals in the runoff from two periods when runoff was collected are presented as mean values and standard deviations of the three samples from the two runoff periods. For the painted materials and the PVC material are the concentrations in the runoff for the two runoff peroids presented separately because of the lrge difference in concentrations between exposure periods.

3.1 Zinc

Significantly higher concentrations of zinc in the runoff compared to the inert polyethylene surface were observed for galvanized steel and Aluzink, see Figure 1 and 2. Zinc concentrations in the runoff from the paints which contain zinc were considerably higher compared to the inert surface and were of the same magnitude as the runoff from the galvanized steel and Aluzink surfaces. However, the differences are considerable between the runoff periods which indicates that the values may not be representative for average concentrations in the runoff from surfaces exposed for longer periods.

It should be noted that the concentration in the runoff from the inert surfaces during the runoff period in April-May 1997 are remarkably high, however, similar values have been reported in rainwater in industrial environments [3] and in roof runoff from residential houses [4]. During the runoff period in September the zinc concentration in the runoff from the inert surface was lower, 0.1-0.3 mg/l which is similar to the concentrations found in other studies [5,6]. An explanation of the high zinc concentrations from the inert surfaces in this study is deposition of zinc containing particles. A possible emission source could be the dense traffic on the road close to the exposure site, which give rise to abrasion of tires containing zinc oxide.

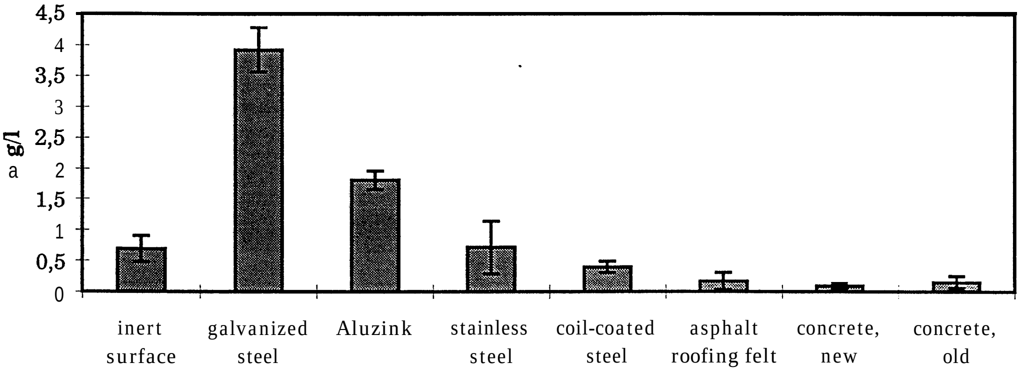

Figure 1. Concentration of zinc in runoff from different materials, exposure April-May 1997.

From materials such as the asphalt roofing felt and the concrete the concentrations of zinc in the runoff lower compared to the inert surface. This is probably due to adsorption of the deposited zinc ions on these surfaces, which is to a large extent influenced by the pH in the runoff and the acid-base properties of the surfaces and the metal ions [7]. In the study mentioned above, the pH in the runoff from surfaces of asbestos cement [5] was slightly alkaline, which is probably true also for the concrete surfaces in this study. The sorption of metal ions on the materials is also influenced by the roughness of the surfaces and the porosity of the materials. This can account for a part of the capability of concrete surfaces and the asphalt roofing felt to retain metal ions. The fact that lowering in concentrations in runoff was not observed for the other metals in this study can probably be explained by the differences in pH-dependence of the adsorption of the cations of the metals.

The amount of zinc released from the galvanized steel during the exposure period was estimated at 120 mg/m^2 if the amount of zinc in the runoff from the inert surface is subtracted. This corresponds to 5.5 g/m^2, year which should be compared with the corrosion rates in Stockholm measured by the Swedish Corrosion Institute which are approximately 3.6 g/m^2, year during 1995-97. The values of metal runoff obtained under the present conditions, i.e. 45° inclination, facing south, is probably representative of a higher value of runoff compared to surfaces with other orientation and inclinations. Other studies [S] have shown that the corrosion rates can differ up to five times for surfaces with different inclination, orientation and degree of sheltering.

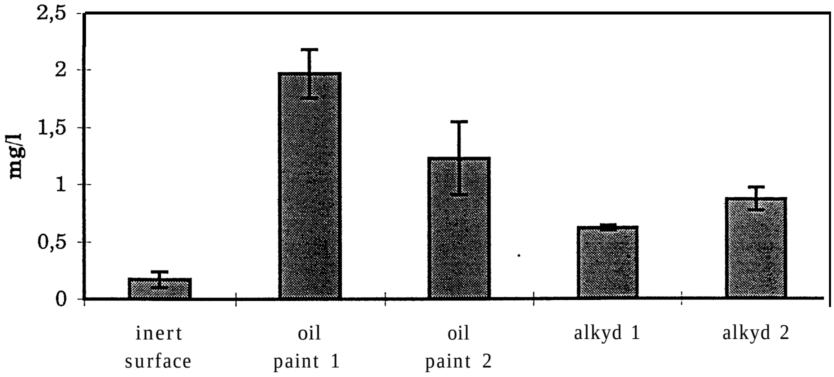

Figure 2. Concentration of zinc in runoff from inert surfaces and materials painted with oil paint and alkyd paint for two runoff periods (denoted as 1 and 2), exposure September 1997.

3.2 Cadmium

As seen in Figure 3 increased concentrations in runoff were not observed for any of the materials investigated in this study. However, in an analogous way as for zinc runoff from asphalt roofing felt and concrete surfaces, also lower concentrations of cadmium were found compared to the inert surface and the other surfaces. The chemical behaviour of cadmium is in many respects similar to zinc and the lower concentrations can be explained by the adsorption of cadmium ions on the surfaces of the materials. The cadmium concentrations are similar to the values reported in the study by Quek and Förster [5], where the effect of lowering of cadmium concentrations in runoff was observed for surfaces of asbestos cement and gravel.

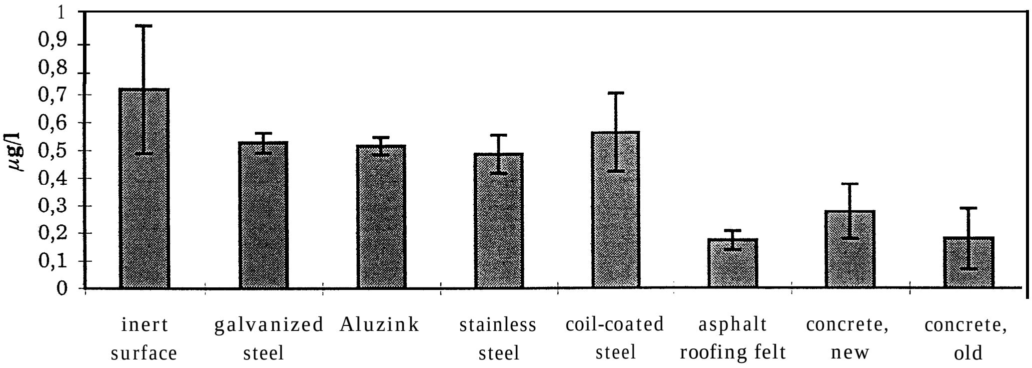

Figure 3. Concentration of cadmium in runoff from different materials, exposure April-May 1997.

3.3 Lead

The concentrations of lead in the runoff given in Figure 4 and 5 show that elevated concentrations compared to the inert surface were only observed for the lead containing PVC materials and the red lead based oil paint. For the PVC material and the painted material significant differences were observed between the first and second runoff period, possibly because of a decreased content of lead compounds in the outer layers of the materials due to the rapid dissolution in the beginning of the exposure period. The lead concentrations for the inert surface were similar to the values in rain bbtained in the studies mentioned above [3,5].

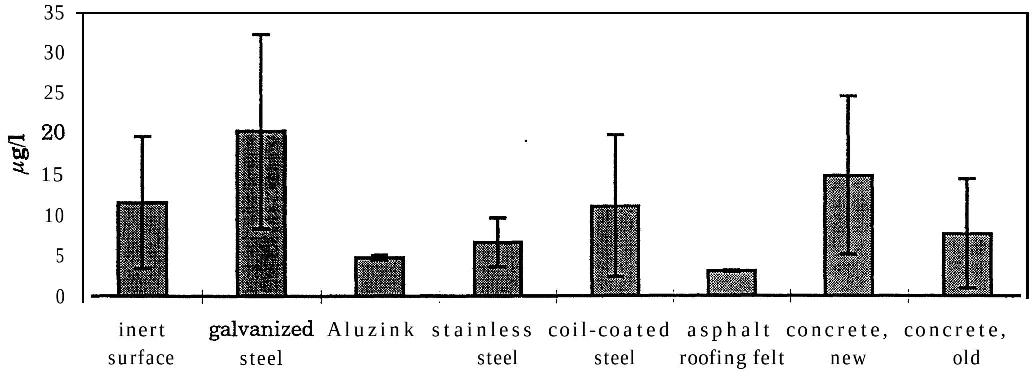

Figure 4. Concentration of lead in runoff from different materials, exposure April-May 1997

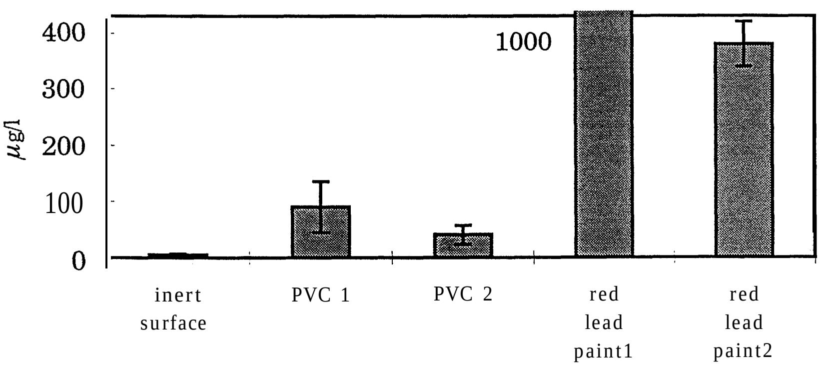

Figure 5. Concentration of lead in runoff from inert surfaces and materials painted with red lead based oil paint and from PVC for two runoff periods (denoted as 1 and 2), exposure September 1997.

3.4 Chromium

For chromium, higher concentrations in the runoff were found for the Aluzink material, which is chemically passivated and for the new concrete tiles. The natural chromium content of cement is about the same as in the earth crust and are depending on raw materials used, usually in the range of 10 to 100 ppm. The older concrete tiles did not exhibit elevated emissions of chromium probabaly because of the lower content of soluble material in the outer layers of the material. The chromium released from the concrete is both in the form of dissolved ions and as particles, probably most in the latter form, but these are not discriminated in the analysis performed in this work. Very low concentration of chromium were found in the runoff from stainless steel.

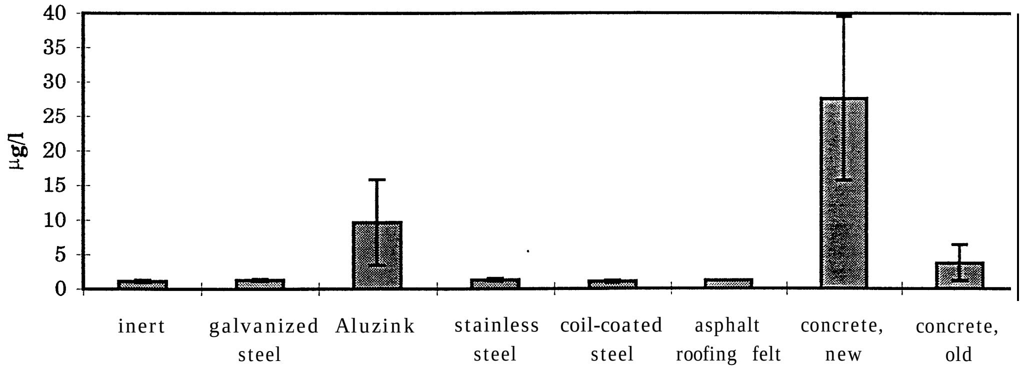

Figure 6. Concentration of chromium in runoff from different materials, exposure April-May 1997

3.5 Nickel

Nickel was found in higher concentrations compared to the inert surfaces in runoff from asphalt roofing felt and from the older concrete tiles. Nickel concentrations in asphalt higher than 1000 ppm have been reported [9] and nickel emissions from the asphalt roofing felt arise probably from the natural content of the material. The source of nickel in the runoff from the older concrete tiles is unknown, but the nickel may origin from raw materials, from contamination in the iron oxide pigments or from added metal slag used as filler. This illustrates the fact that concrete constructions and products in this respect can not be treated as materials with uniform composition and content of metals.

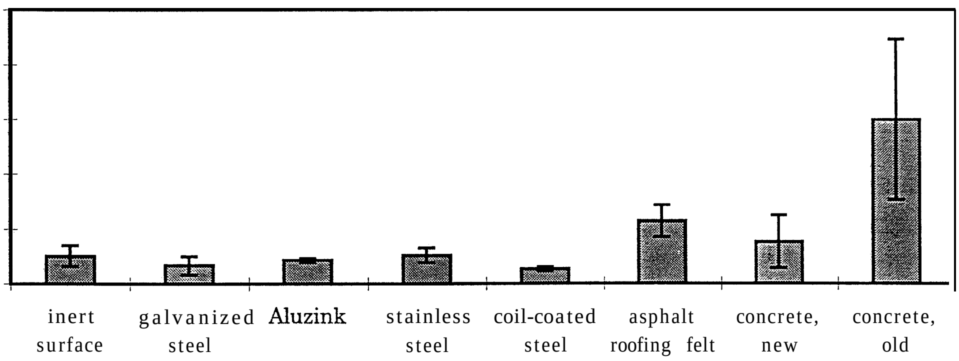

Figure 7. Concentration of nickel in runoff from different materials, exposure April-May 1997

3.6 Copper

The copper concentrations were all quite similar for the different materials except for the concrete tiles for which significantly higher concentrations in runoff were observed for the older concrete tiles. The copper concentrations from the inert surfaces were similar to the values in rain obtained in the study by Quek and Förster [5]. Further studies are currently performed on copper surfaces on buildings in order to determine metal emission rates from copper roofing materials during longer exposure periods.

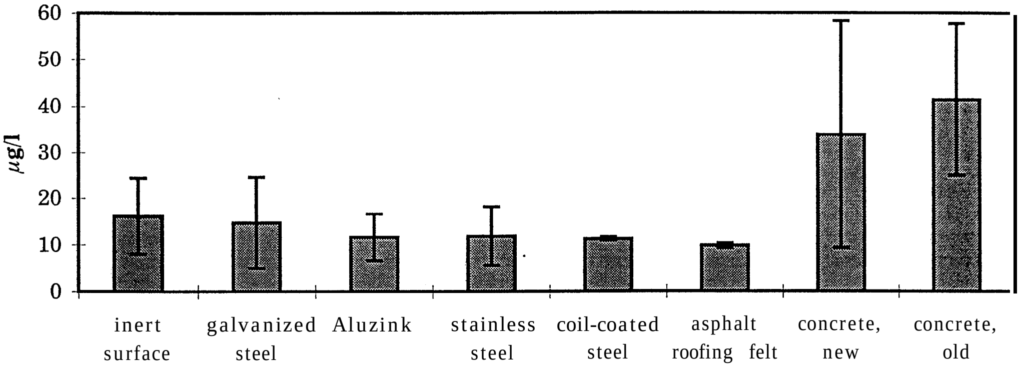

Figure 8. Concentration of copper in runoff from different materials, exposure April-May 1997

4 Conclusions

Investigations of runoff from different building materials have been performed and elevated concentrations in runoff were obtained for zinc from galvanized steel, Aluzink and zinc containing paints, for lead from PVC surfaces and red lead based painted surfaces, for chromium from new concrete tiles and chemically passivated Aluzink surfaces and for nickel from asphalt roofing felt and older concrete tiles and for copper from older concrete tiles. The concentrations of zinc and cadmium in runoff from concrete surfaces and asphalt roofing felt were lower compared to the concentration in runoff from inert reference surfaces of polyethylene, probably as a result of adsorption of zinc and cadmium ions on the former surfaces.

The emission of heavy metals due to corrosion and degradation of materials is a complicated process and is dependent on severals factors such as levels of air pollution, rain chemistry and intensity, inclination and orientation of the surfaces and the age of the material which can lead to build-up of protective layers or depletion of the surface layer of the material. The data collected in this work were obtained during relatively short runoff periods and thus does not permit any conclusions about the rates of metal emissions over longer periods of exposure. Further studies will be performed on materials surfaces on buildings and other constructions over longer exposure periods in order to determine metal emission rates that can be used for- estimation of metal flows from materials to the environment

5 References

1. Stigliani, W.M., Jaffé P. R. and Anderberg S. (1993) Heavy Metal Pollution in the Rhine Basin,. *Environ. Sci. Technol.* Vol. 27, No. 5, pp. 786-793.
2. Naturvardsverket, (1994) *Metaller i stad och land - kretslopp och kritisk belastning,* forskningsprogram 1994/94 1998/99 (in Swedish)
3. Thomas, P. R. and Greene, G. R. (1993) Rain Water Quality from Different Roof Catchrnents. *Wat. Sci. Tech.,* Vol. 28, No. 3-5, pp. 291-299.
4. Chang, M. and Crowley, C. M. (1993) Preliminary Observations on Water Quality of Storm Runoff from Four Selected Residential Roofs. *Water Resources Bulletin,* Vol. 29, pp. 777-783.

5. Quek, U. and Förster, J. (1993) Trace Metals in Roof Runoff. *Water, Air and Soil Pollution,* Vol. 68, pp. 373-389.
6. Verbiest P., Waeterschoot, H., Racek, R. and Leclerq M. (1997) Zinc and the Environment: A Study of Run-Off and Corrosion of Rolled Zinc Sheet in Different Exposures, *Protective Coatings Europe,* pp. 47-60.
7. Stumm, W. (1992) *Chemistry of the Solid Water Interface.* John Wiley & Sons, New York.
8 Rendahl, B., Kucera, V., Vlckova, J., Knotkova, D., Norberg, P. and Sjostrom, C., (1996) The Microenvironment and Corrosivity in Different Positions on the Royal Palace in Sockholm and on Prague Castle. *Durability of Building Materials and Components,* 7 (volume one), Ed. Sjöström, C., E & FN Spon, London, pp. 219-232.
9. Malmquist, P. -A., (1983) *Urban Stormwater Pollutant Sources,* Thesis, Dept. of Sanitary Engineering, Chalmers University if Technology, Gothenburg, Sweden.

An Assessment Protocol for Historic Wooden Buildings

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Abstract
In all countries with historic wooden building tradition, investigations, assessment and documentation of wooden building parts are executed in rather similar ways. National differences are mainly existing for the reason of maintenance skills and modernization measures. Lack of inspection, lost .of carpentry skills and impropper modemization measures are nowadays the main reasons for damages. Changes of building parts and applications made it necessary to evaluate climatic and environmental conditions new.
Anassessment protocol 1s developed as a harmonized system for maintenance tasks of wooden constructions. It includes the interdisciplinary approach for investigation, planning and documentation as well as the concerning techniques. In Germany, Norway, Sweden and Poland practice has been researched and components which are reasonable to be part of „the system" were adopted. The result of this eclectic and supplementing approach was multidisciplinary discussed on workshops at „pilot" buildings of the participating countries. The assessment protocol was developed on the occasion of the tasks at this buildings including representatives of the target users.
The assessment protocol refers to four different user levels of owners and inspection personnel, of architects and other „generalists", of wood specialists and of scientific and „calibrating" persons. The assessment is structured in aspects, like construction and static, wood substrate and also treatments. For each combination of this aspects and user levels adequate working tools are given. The system structures also the timely development of the various tasks during a restoration project and in the course of the subsequent maintenance phase of a building.
Documentation takes an important role for the integration of various results of investigations, assessment and planning and the information transfer to the concerned parties. A key role plays the hierarchical ,,orientation system", which is a code system of the building to link information. A legend for the condition mapping and an atlas with standardized damage types and damage degrees are examples for documentations under user level 2 and 1. Algorithm for the use of this and other tools are developed and prepared for a PC-based application on a geographic information system and a handheld-computer for data collecting on site.
Keywords: historic wooden construction, inspection, documentation, maintenance

1. Introduction

1.1. Wooden building stock and practice of maintenance

1.1.1. Characterization of the Wooden Building Stock

In the historical development wooden construction types became comparable structures all over the world due to climates, resources and use. Even reactions to occuring weak points in the construction were managed in similar ways. In the past there were enough experience which made the maintenance sure in technique and esthetic. Today the building trade and environmental conditions are changing rapidly, there is no time for evolutional development. We are concerned with historic wooden constructions like roof constructions, ceilings, towers, bridges, foundations and mainly half-timbered houses and log buildings with different coverings. In all countries with historic wooden building tradition, investigations, assessment and documentation of wooden building parts are executed in similar- approaches and techniques. National differences are mainly existing for the reason of maintenance skills and modernization measures for nowadays living comfort.

1.1.2. Problem Situation

Wooden buildings have a long history of repair techniques, mostly executed by carpenters. With a well developed maintenance-program the durability of wooden buildings can be several hundred years. Lack of inspection, lost of carpentry skills and impropper materials and modernization measures are the main reasons for damages. Due to changes of building parts and applications it became necessary to evaluate the construction, the climatic condition and the environmental impact new. The situation of about two million German half-timbered-houses is exemplary [3]: In the seventies the interest in protecting these buildings increased and additional requirements for better energy-saving, sound insulation, etc. improved. The removal of plasters and other claddings of the fassade in order to show the wooden construction became en vogue. These conditions together were combined with wrong assessment and improper maintenance-measures. The results were damages and loss of historical building substance.

1.1.3. Investigation, Assessment and Documentation

The causes and motive to define a project for restoration and rehabilitation can differ in a wide range: damages, new requirements for the use of the building or changes of the building and its use are common. A systematic approach is very necessary to keep the budget in limit and to avoid loss of original building substance. The uncertainties about the condition of historic buildings are great. These facts are the reason of the importance of investigations. Although the importance is evident, investigations should not been executed for its own sake. In practice in nearly all restoration projects it is necessary to build up a documentation from its beginning. Fundamental research in archives and files is an - often not understood - urgent need to avoid unnecessary investigations. It is common, that the informations are not linked, they are widespread over the owner, architects, officials, restorators, special experts, craftsmen, etc. due to their different aims. It would be ideal to work on a harmonized concept to acquire and update data continualy in long terms.

1.1.4. Maintenance and Restoration Projects of the Buildings

Historic buildings should have a continuous maintenance with small remedial measures for restoration and conservation as far as necessary. The various terms in the monument preservation give an impression of different activities: maintenance, repair, rehabilitation, restoration, conservation, technology of saveguarding, renovation, restoring, replacement, reconstruction, rebuilding, etc. [2]. Projects, approaches and measures must adjust to the philosophies and requirements behind these terms. Monument preservation has a rich history and regional very different shapes that make a „harmonized system" for an assessment protocol difficult.

1.2. Objectives

An assessment protocol should be a computer aided guideline for inspection tasks and the preparation of restoration projects. For the basic information it is necessary to categorize types and degrees of damages, harmonize phases and levels of investigation, describe investigation methods, define a system for graphical condition mapping and make the assessment rules clear. Of great importance is, that the requirements of the target groups and the implementation in their organizational environment is taken into consideration.

1.3. Methods

In Germany, Norway, Sweden and Poland practice has been researched and components which are reasonable to be part of „the system" were adopted (e.g. [1]). It can be understood as a interim bottom-up solution of best practice, because up to date there is no international harmonized solution achievable. The result of this eclectic and supplementing approach was multidisciplinary discussed on workshops at „pilot" objects of the participating countries. The assessment protocol was developed on the occasion of the tasks at this buildings including representatives of the target users. The pilot objects were wooden buildings in Ebersbach (Germany), Lillehammer (Norway), Stockholm and Gävle (Sweden) and Swidnica (Poland). There were not more time then three days at every object.

New technologies, like the geographic information system „Arcview", and an inspection handheld computer, were also adapted in a pragmatic way to work on solutions of best knowledge and conscience. The team handled the challenge to be multinational and multidisciplinary.

This approach was choosen to get results in this rather complex working field in the frame of one comparatively small project. For that reason the result is scientificly a thesis, in an economic view it could be a first step towards a product.

2. Content and Background of the Assessment Protocol

2.1. Structure of the Assessment Protocol

The assessment protocol is a harmonized system for the maintenance tasks of wooden constructions. It includes the interdisciplinary approach in investigating, planning and documenting as well as the concerning techniques. The assessment protocol refers to four different levels of owners and inspection personnel, of architects and other „generalists“, of wood specialists and of scientific and „calibrating“ persons.
Part of the assessment protocol are information about causes for investigation, investigation techniques, assessment rules, documentation, procedere at objects and maintenance management, examples and references, as well as information about the implementation and use of the system in the organizational environment.

2.2. Assessment Background

2.2.1. Assessment Aspects

To investigate a building means to search for the reasons of its conditions with the aim for predicting the long term condition after executing a remedial measure. The phenomenons have to be categorized, whether they are depending on the construction, on the materials or on chemical applications. Basic assessment procedures are structured in 5 assessment aspects, some examples are given. The detailed assessment criterias are beyond the frame of this paper.

- construction
    - load bearing principles
    - cracks, fractures, deformations, squash, fixtures, joints, etc.
    - constructive wood protection against moisture diffusion and weathering
- timber condition, destroying agencies, wood substrate
    - wood quality
    - fungies and insects
- wood preservative chemicals and paintings
    - wood treatments (tar oil, water-borne, organic solvent, etc.)
    - paints (cracking, flaking, blistering, fading, chalking, etc.)
- adjoining materials
    - fillings in half-timbered houses
    - rising moisture from the ground
    - waterproof layers in connection with wood
- environmental aspect aund climatic conditions
    - phenomenons due to weathering (i.g. driving rain)
    - use (heating, unused rooms, etc.)
    - nearby trees, climbing plants, etc.

2.2.2. Typical Building Parts

Assessment rules are also necessary for more complex building situations: e.g.: in the course of rehabilitation of half-timbered fassades, it is often a „historical“ guided aim to take the covering plaster away to show the wooden construction. A secound aim is also to add a heat insulation on the inner side. Research has shown that such facades should yearly not have more than 140 Liter/m² driving rain. In addition diffusion must be able to the inner side. Air in the wall can have very negative effects, because they interrupt capillarity. Requirements borrowed from standards for modern waterproof facades lead up to use sealing materials which are partly the sources of damages on half-timbered facades. These „assessment rules”, and a lot more constellation of moisture limit values and relations are necessary besides the elementary assessment via the aspects of the previous chapter [3].

2.2.3. Predictions for the Conservation State and General Design Rules

Calculations for historic buildings are rather complex, the materials are different from modern ones and material coefficients are not precise known. In addition the construction principles of old buildings are not following the nowadays standards on which our evaluation is based. For this part of the assessment protocol great uncertainties do exist, in practice its the only way to scrutinize the single case by using „experience“.

2.3. User levels

Investigations should be orderd in precise tasks thematically, economically and in the necessary depth. Here is an urgent need in practice. The workshare and synergetic effects between the concerned parties must be improved. The following table gives an overview of the user levels for the assessment protocol.

Level	Purpose	Minimum User Qualification
1	• Inspection (every 1 to 2 years)of weak points at the construction according to plan	identify critical phenomenons, technical education
	• Inspection (every 5 years) planning of renovation, control of adequate use, cost estimates for maintenance measures	architect, facility manager, craftsmen, technician
2	• Inspection (every 10 ore more years) • begin of a restoration project: basis of design and preparation of tenders • system keeper for documentation and integration of experts recommendations • defining the inspection plan	architect, engineer, restorer, facility manager
3	• order of L2 after definition of special tasks	proofed/certified specialist
4	• very difficult and not usual situations • not object oriented research work	scientist, laboratory engineer

2.4. Investigation due to User Levels

The investigations of all aspects can be executed as

- visual investigation,
- visual investigation with the aid of instruments,
- long and short term investigation measurements at the building, investigation on samples in the laboratory and monitoring
- calculations based on investigation results

A matrix of the levels and the aspects of investigations gives for every combination the aims, methods and tools and the characterizing data of the results. Annex to this matrix containing a short overview over the various „tools“. These are ranging from a damage atlas as a calibrating system for visual inspection in level 1 and 2, over the drilling resistance method for timber sections (level 2 and 3) up to microscopy means for level 3 and 4. It is obvious, that tool boxes are defined for each combination of level and aspect that represent common working fields.

2.5. Documentation of Work and Objects

2.5.1. General Role of Documentation

Documentation plays an important role in the preservation of monuments. Documentation can become a „secondary“ monument when the building is destroyed. Layer techniques on basic drawings and maps are coming more and more to use for the multidisciplinary preservation task. Documents (text, fotos, drawings) on every scale occure and have to be stored. There is neither an international nor an national standard to harmonize the island solutions for the different documentation tasks. A common data base could be ideal, but the question who the systemkeeper could be is very difficult. All who are working at objects are making island solution documentations. It is absolutly necessary to pass a structure to all concerned orders by the owner or representative.

2.5.2. Orientation System

Orientation system is a code system, which identifies every building, building part, element, material and, if necessary, every smal spot. It is an urgent need, that this code has a form, that a user can understand and complete it at the object. The different building types demand typical forms, from which easily the individual orientation system for an object can be generated. Following this the assessment protocol is concerned with:

- generic orientation system (general definition rules)
- specific orientation system (half timbered houses, log houses, etc.)
- individual orientation system (single individual buildings)

2.5.3. Information and Documentation Structure

The assessment protocol is open for various documentation systems. Regional or organizational requirements are acceptable. Three elements are building up the basis of documentation:

- orientation system (code and links)
- object data sheet (basic data of the object)
- system for condition mapping (condition visualization; samples, photos and comments „user surface“)
- inspection question and results

It is obvious that all information are with strict time series information.

3. Application of the Assessment Protocol

3.1. Computer Aided Assessment Protocol

A geographic information system was choosen as the PC-based platform for the assessment protocol. On the GIS are all elements with the basic knowledge for restoration projects and all, which are necessary to do the assessing work in the maintenance inspection sampled.
For the reason of various target groups it can only be a modul system, containing e.g.:

- measurements database on ,,geographical scales“
- modules for characterizing and mapping of the exposure risk factors
- information and user guides for investigation, documentation and assessment
- examples, containing specific results and experiences of objects.

A complementary inspection system has the following moduls:

- handheld computer and main computer program for handling observations at the building site
- library for condition assessment of wood, containing the structure, questions and answers linked to observations of damages on wood

3.2. Consequences for the PC Assessment Protocol in Practice

3.2.1. Possible System Keepers and Organizational Prerequisites for the System

The vast possible system keepers or users make clear that the system can only be a component system: facility managers, owners, architects, restorers, engineers, offcials, funding institutions, education institutions.

3.2.2. Workflow at Objects

The workshare and organizational environment of the system keepers and experts, which deliver information to the system, has to be taken into account to reach synergetics. This means that not only the pure content but also the acceptance and implementation of the assessment protocol is of great importance. For that reason a standardized networkplan is developed, which gives a frame that can be adopted for restoration projects. It distinguishes the 9 following phases. Each of the phases contain between 10 and 20 serial and parallel activities. The activities are subdivided by checklists for various aspects of economic, technique and organization. The connection to the documentation is checked within this system. The items of the check list have information leaflets as far as necessary.

Phases of the standardized network-plan:

1.) development of the project (orientation, objectives, feasibility check)
2.) object identification (acquiring the basic data, responsibilities)
3.) objective analyzation (user requirements, necessary investigations, first concept for the building)
4.) building and condition survey (orientation system, building history research, condition assessment, correlation of results)
5.) restoration and rehabilitation concept (utilization, general concept, building component measures, priorities, test application, monitoring, consequences)
6.) commitment and execution of remedial measures (drawings, descriptions, time scale, tenders, cost planning, placing, execution of work)
7.) acceptance and final documentation
8.) starting the maintenance management (user guide, inspection concept, responsibilities)
9.) maintenance (inspections, assessment algorithm, service and repair)

4. Conclusion

A concept for a PC-based assessment protocol for historic wooden buildings has been developed. The lack of harmonized regulations and working tools became obvious. For all that it was possible to reach a harmonized working platform. The next step should be to work on objects, included in their daily practice. The sticking point is the acceptance and implementation of the svstem in pilot user organizations.

5. Acknowledgements

The European Comission made it possible to start this work in the frame of the project WOOD ASSESS under their Environment and Climate - programme by partwise funding. The assessment program was workpackage 1 in this project. Gratitude should be given to the new built international and interdisciplinary team that was able to handle this complex challenge with great commitment.

6. References

1. Norwegian Standard 3424 (1995). Condition survey for construction works - Content and execution. *Norwegian Council for Building Standardization*
2. Petzet, M. (1991): *Grundsätze der Denkmalpflege / Principles of Monument Conservation / Principles de la Conservation des Monuments Historiques.* ICOMOS, Journals of the German National Committee. München
3. Veit, J. (1996): Feuchteverhalten von Fachwerkfassaden. *Bauhandwerk* Vol. 1996, No. 6, pp. 3 1-34

Longtime performance of plastered external walls made from autoclaved aerated concrete

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ABSTRACT
The article describes the state of the art in this Swedish project, aiming to identify degradation factors and mechanisms of plastered AAC wall systems. The scope covers both inorganic and organic based plaster systems intended for exposure in some European countries for a period of 5 years, with the final goal to predict durability and service life from research work following the methodology provided in CIB/RILEM technical recommendations and IS0 standards.

The article describes the various parts of the project, the performance criteria and characterisation of materials used in the system. The main part of the article refers to observations and conclusions made from experiences and field inspections of thin plaster systems applied to industrial buildings in the area of Örebro and Kumla. Observed damage types and possible degradation processes in organic and in-organic based plaster systems are described and discussed.

Based on theses studies it was concluded that inorganic plaster systems generally degrade to a lesser degree than organic systems. The duration and level of moisture content in the surface area are seemly a very important reason for the increased risk of degradation; inorganic systems seem to stay dryer in the outer part of the walls between periods of saturation. Another important factor is that the difference in need for maintenance between different plaster systems is not often considered by asset owners. Design detailing is also very important to achieve durability and long time performance. The micro climate on building facades in combination with unexpected effects of detailing are seemly much more important for degradation processes than knowledge of the average macro climate in the area.

Finally some future research work is outlined and some possible degradation mechanisms are provided for organic and inorganic plaster systems.
Keywords: Autoclaved Aerated Concrete, Durability, Plasters

1 Introduction

1.1 Background

Autoclaved Aerated Concrete (AAC) is a commonly used building material all over the world. In Sweden, AAC is mainly used in the external shell of buildings and the external walls are often plastered as an aesthetic and protective measure. As for most materials, research work for AAC has usually concerned mechanical and physical properties in fresh material. Little is known about the degradation processes of AAC and the system plastered AAC under long time exposure to environment. The aim of this Swedish project is to identify degradation factors and mechanisms of plastered AAC wall systems based on long term exposures and accelerated short term ageing tests. The final goal is to predict durability and service life in these systems from research work following the methodology provided in CIB/RILEM technical recommendations and IS0 standards.

1.2 Standards

The methodology and a decision tree for conducting the research work on durability has been developed by CIB/RILEM and subsequently adopted by ISO/CEN. The existing guidelines are in the form of two drafts from ISO/TC59/*Sc14*-DESIGN LIFE. The first two of five documents in the series “Buildings-Service Life Planning” are: “Part 1: General Principles” and “Part 2: Service Life Prediction Methods”. The different steps to be carried out are described in a scheme obtained from ISO/WD 15686-2.2.

2 Project Definition

2.1 General

Within the overall project the degradation in plastered AAC systems will be determined at an European level. The AAC material in the exposures will be taken from one single factory and will be combined with a number of organic and in-organic plasters. The whole project consist of a number of sub-projects whereof the ongoing projects are mentioned later in the text. Exposures in different climates in Europe and related laboratory tests will start in 1998 and continue for a period of 5 years. The intention for the final work of the project, comprising all the steps in ISO/WD 15686-2.2, are to establish damage functions for the systems being studied.

2.2 Performed project parts

The following project parts have been carried out by researchers from the Royal Institute of Technology, Gävle and those from the industry involved in the project.

- A pre-research project was started in the autumn of 1995 by Yxhult AB and KTH, with laboratory tests in order to determine suitable methods for measuring moisture in AAC walls under field conditions.
- In October 1996, Yxhult AB and Optiroc AB, equipped a part of a plastered wall to a house in Kungsbacka, Sweden, with instruments for continuous monitoring of moisture conditions and surrounding climate for one year.

- In August 1997 the second part in the project just mentioned was started by laboratory testing of physical properties of 12 different plastered systems. Tests for water vapour diffusion and water uptake were completed and freeze-thaw tests are being conducted.
- In December 1997 a first inspection of industrial buildings in different ages was carried out in the area of Örebro and Kumla, Sweden, with the aim to verify the status of different systems of plastered AAC components.
- As one of three sub-projects, microscopy technique is being developed for a potentially more accurate and quicker analyse of physical material data. The other sub-projects deal with the effects of water repellents to the properties of plastered or non-plastered AAC and as well, the development of mathematical models for moisturing flow processes in the system plastered AAC.

2.3 Field exposures

The intention for the choice of environment for field ageing exposures are to give the spectra of the outer limits for some systems of plastered AAC. The different climates for planned exposure tests stations have been chosen mainly considering the amount of precipitation, range of temperatures, solar radiation and pollutants such as SO_2 and NO,.

The field stations shall be designed as ventilated and heated, closed cabins. Monitoring of temperature and moisture conditions in and on the exposed plaster systems will be carried out continuously. Material analysis will be done yearly based on drilled cores taken from the test samples. The first reference exposure station will be built in the first half of 1998 in Gävle, Sweden. RH, UV-diffuse and global radiation, wind speed and direction, precipitation and SO_2 and Cl- contents can be measured at this site.

2.4 Specification of performance criteria

The function fulfilled for external walls are in general terms loadbearing and / or as protection against the climate as well as architectural values.

In this project identifying of early warnings of degradation related to properties and composition are a central interest and may lead to developing criteria for maintenance needs and estimating renewal costs. Inspections of buildings may give the pattern of damage types and possible degradation mechanisms.

The performance criteria for the system plastered AAC should be based on loss in physical properties, loss in protection against weather factors and loss in appearance. Properties that are of interest to measure are water vapour permeability and water absorption rate. Loss in these properties to a certain extent may serve as a basis for a classification of plaster systems. Micro cracks and chemical decomposition in the system are early warnings to these degradation mechanisms. Loss in strength can also be judged by direct measurements. Loss in aestetic performance can be judged by a classification system that considers colour degradation, gloss loss, fungus and algae growth and cracks.

Critical values of the properties previously mentioned depends on the type of plaster system and the intended in-service environment for the system.

2.5 Characterisation of materials

2.5.1 AAC

AAC is formed mainly by siliceous fine materials, usually fine ground sand, calcareous materials such as lime, cement and / or minor amount of additives like gypsum. The materials are mixed in water and the slurry is cast into steel moulds and rised by hydrogen gas from the reaction of aluminium, powder or paste, in the alkaline slurry. Finally the curing is performed by an autoclaving process, saturated steam at roughly 12 bar and 190 ^oC.

AAC is recognised by its high porosity, ca. 80 % of the volume consists of pores. The pores are usually classified as micro capillary, macro capillary and air pores. The first two classes of pores include pores with diameters from ca. 10 nm to 100 μm and correspond to about 40% av the pore volume.

Chemically, AAC consists of calcium-silicate-hydrates and oxide compositions. The pH-value, ca. 10 in the fresh material, is less than in dense concrete. The structure in MC, is micro-crystalline and formed mainly by tobermorite platelets which are more stable than normally cured concrete [1].

2.5.2 Plasters

2.5.2.1 Organic plasters

Organic plasters for AAC are normally based on an acrylic resin binder with siliceous fillers and grains forming the surface texture. The normal system in Sweden consists of two treatments and starts with a primary coating followed by a secondary spraying of the surface with a texture forming layer. The recommended weight of plaster material to apply is at least 1.8 kg/m^2.

2.5.2.2 Inorganic plasters

Before the 1980´s, a two-layer lime-cement mortar was often used in Sweden as a thin plaster system. The first layer was cement rich in comparisson to the subsequent layer to strengthen the surface of AAC and to prevent moisture suction from the fresh mortar applied as the second layer (total thickness of maximum 3 - 4 mm). The second layer served as the aestetical treatment forming the texture. For dwellings usually thick, three layer lime-cement plasters are used (total thickness of 12 - 20 mm), especially for block walls.

3 Degradation agents

Degradation agents are listed in IS0 6241: 1984, Table 4. The agents are classified according to their own nature and origin, as mechanical, electromagnetic, thermal, chemical and biological. All agents reported in the CIB W80/RILEM140-PSL report “Environmental Characterisation including Equipment for Monitoring” [2] are applicable and possibly involved in the degradation processes of plastered AAC. However moisture, temperature, UV-radiation, air pollutants and acid rain likely forms the most active part in the degradation process for plastered systems.

4 Field inspections of built environment - industrial buildings

4.1 General

Inspections of the status of build environment is an important part in the process. **A** first inspection of industrial buildings have recently been carried out in the close surroundings of Örebro and Kumla. These inspections and experiences from many other single inspections have made it possible to formulate some conclusions over the degradation process in thin layer plaster systems. The buildings studied included light mechanical industries or office buildings. All buildings had a normal heated, indoor climate and seemingly dry activities.

4.2 Systems

The component system observed in the field inspections consisted of homogenous reinforced AAC wall components coated with thin organic or inorganic plaster systems. The AAC materials in the inspection round had various ages and therefore different densities. Due to the adoption of higher requirements in thermal properties in Sweden, most delivered components had a dry density of about 390 kg/m³ after the end of the 1970's. Before that time, normal dry density of such components was about 480 kg/m^3.

4.3 Specification of environment

The environment at a macro and meso (urban) level in this region of Sweden is characterised as an inland climate with moderate SO_2 levels ($< 20\ \mu g/m^3$) and driving rain of 300 kg/m^2 (annual mean value) and a maximum day and night mean value of 45 kg/m^2 [3]. The landscape is flat with an open terrain. Orebro is located 5 1 m above SL and at the following geographical position: Lon. E $15^o3'$, N$59^o15'$. Analysis of rain pollutants is not yet available.

4.4 Selection of buildings

The buildings were chosen in an area with as uniform environment as possible. From each decade beginning in the 1950, 5 representative buildings were chosen in order to see possible changes in behaviour of the systems due to age, plaster system and different composition of AAC. The plasters applied were of different chemical compositions. Among the buildings inspected there were lime-cement plasters as well as organic plasters with acrylic binders. All plasters were, however, of the thin art masters with thicknesses varying from 1 to 4 mm.

4.5 Sampling of information

The presence of algae growth, crack types and widths, mechanical and structural damages around the buildings was documented made by photos, video tapes and notations. Frequent measurements of the moisture conditions in the outer 15 mm of the AAC material were carried out in different heights around the buildings by a conductance type electric moisture meter equipped with non-insulated pin-electrodes of 15 mm length. Sampling of other building information such as year of construction, wall thickness, AAC density and indoor climate was also carried out.

4.6 Damage types

4.6.1 Algae growth, fungi growth and discolouring by fungus

Most algae growth was noticed on organic plasters. The algae attacks were noticed especially in North and North-East facades together with the indication of a high moisture content. Especially severe algae growth was observed on several base elements. Discolouring was noticed in organic plasters in the same facade directions as mentioned. Fungi growth, lichen, was noticed on a few buildings, but only on mineral based inorganic plaster systems. The reasons for the difference in the level of fungal attack when comparing organic and inorganic systems may be that inorganic plasters have an alkalinity that restricts fungal growth and as well are on average kept dryer.

4.6.2 Cracks

In systems with inorganic plasters there were very few cracks observed. The surface moisture content indicated in these systems were relatively low at the inspections and were of the same magnitude in unprotected damaged spots as in plastered areas. The conclusion from this is that these systems are open for moisture diffusion and moisture absorption and that the system do not contribute to a built up moisture content. The duration of a moist state is also likely shorter than in organic systems.

Systems with organic based acrylic plasters showed a high variety of crack patterns. Some buildings were free from cracks and other showed many cracks. South and West facades were the most cracked sides and particularly the bottom base elements up to number 2-3 were cracked. Components bridging over longer openings were also often cracked. Very few buildings were maintained by repainting. Thus most buildings with organic plasters, also from the end of the 1980’s showed the need for renewal of the plaster. Indicators for maintenance need included beside cracks, chalking and colour loss.

4.6.2.1 Crack patterns

4.6.2.1.1 Vertical cracks

The most frequent type of cracks in horizontal components were vertical and regularly spaced within the length of the components. The width of the vertical cracks were mainly 0.05 - 0.20 mm. In inorganic plastered components very few cracks were noticed.

4.6.2.1.2. Horizontal cracks

Horizontal cracks were related only to organic systems and near the horizontal reinforcement or the centre line of the components. The actual facades for these type of cracks were South and West facing. The indicated moisture content in these parts of the facades where generally higher than in other sides of the same building.

4.6.2.1.3 Irregular crack pattern

This type of crack pattern was only related to organic plasters and especially to highly moistured parts of the facades. The crack width were of 0.05 - 0.10 mm in size. This type of crack pattern in walls seemed also to be more frequent in areas of the building without heating.

4.6.2.1.4 Structural/design cracks
Structural cracks due to mistakes in design and unsatisfactory work were clearly evident and could be seen where joints between building parts were sealed with a too stiff sealant product or having an improper width. Also damages of components supported on wrongly designed steel plates was common.

4.6.3 Freezing damage
Freezing damages were rare, but more evident in buildings from the 1960's. In the surfaces to a framing of an industrial door, typical unevenness in the AAC surface was noticed in the damaged parts and also small micro cracks. An other freeze damage, crack and tendency of splitting, was noticed in a base component in contact with a snow-drift.

4.6.4 Mechanical damage
A considerable number of locations where mechanical damage was evident was observed on the entrance sides of buildings. Normally there is an asphalted transport surface on one side of an industrial building. These areas generally cover the ground close to the base components due to transports through the doors to the manufacturing locals. The damages noticed are derived from trucks, damages from pallets and steel sheets against the walls, snow clearance machines and so on. All these damages could be avoided by careful design and by considering barriers in front of the walls.

4.6.5 Blisters
Blisters were noticed only in one case. It was in an organic acrylic system and the reason were judged as a combination of a too water vapour tight system and a high humidity in the wall. Some blisters were cracked and had peeled off.

4.4.6 Peeling
Peeling of the plaster was noticed in the case mentioned before under blisters and also in some other buildings where the degradation of the surface had not been repaired.

4.4.7 Dirt
Dirty components were noticed where elements were used in base components due to splashes from open ground or asphalted areas.

5 Conclusions of field inspections

5.1 General
Though the climate in the region of Örebro is considered moderate, the visible effects of a more severe micro climate were found to dominate in all damages seen in the inspection of buildings. Especially the parts of the wall close to the ground level were often attacked by algae, moisture and cracks. Since crack formations were frequent the reasons therefore should be further investigated. The higher density and strength in old AAC components had further a positive effect to the level of damages in organic plaster systems but usually the same pattern and importance of the location are valid.

5.2 Degradation due to type of plaster

Inorganic plasters showed the best performance in the inspections and very few signs of degradation were observed. The moisture properties in these systems therefore seem to be suitable in moderate climate. Visible damages in these thin systems were seen as vertical cracks from shrinkage, which in comparison with those in organic systems were much more widely spaced. The observations of surfaces in connection with cracks gave no signs of deterioration in inorganic systems. The reason therefore is probably a levelled moisture content over the surface independently from eventual crack formations. Inorganic plasters also have a good tensile strength and a thermal expansion close to that of AAC.

Organic plasters, acrylic based, showed many types of degradation patterns and most of them were cracks and algae attacks due to a high moisture content. Observations of surfaces close to crack formations showed in many cases also severe signs of deterioration. The reason for the observed differences in status between inorganic and organic systems seems to be that the time for renewing treatments of organic plasters is much shorter than for inorganic plasters but this fact has not been considered by the asset owners. If regular maintenance had been adopted in accordance with the type of plaster, the problems observed from the inspections would have been much less. You can also say that the sensitivity for degradation affects in this type of organic plasters is much higher than in the inorganic systems studied.

5.3 Degradation due to moisture conditions

Generally it can be stated that the inspections have shown that degradation by environment is always more severe where there is a high moisture content in the surface of the components. The duration and the frequency of the moist states are probably also two very important factors for the degradation rate in a plastered AAC facade.

The highest indicated moisture content during the inspections has been found in acrylic plaster systems, followed by visible signs of degradation such as cracks, peeling and algae growth. The acrylic systems are likely to have a higher moisture content in average than inorganic systems even when the latter might have higher peak values, for shorter times however. The time between attacks from driving rains is of course essential, but the region of Örebro is quite moderate in this aspect. A parallel can also be drawn to analysis by scanning electron microscopy of acrylic paint applied to wood specimens which have shown a great number of capillary pores in the acrylic paint with a diminishing size from surface to bottom that indicates that a capillary suction effect is possible in newly applied systems without imperfections [4].

The maintenance intervals, the detailed design of buildings as e.g. the base height and the performance of the facades are very important factors to consider for durability. These design factors combined with the micro climate in certain points to a building, can affect the plaster system more severely than estimations made from the average macro climate given from weather stations for the area may indicate.

5.4 Degradation due to freeze-thaw damage

Very few damages were deemed to be caused by freezing and thawing. Small localized damage areas were noticed with an origin from freezing at some exposed positions of a few buildings. Non-plastered AAC usually possesses a good resistance to freezing [1] and in this part of Sweden freeze-thaw damage is considered rare which was understated by this inspection. However, in the past in this region, a considerable industrial area with buildings of vertical components were damaged due to freezing effects. In that particular case the water outlets from the roofs were improper designed and the applied organic plaster was much thinner (paint coating) than that required and therefore perforated by pin holes, acting like strainers for water. Other parts of Sweden such as the West coast, have also very few reports of freezing damages. The reason for this can be found in the moisture properties given by the percentage and size of the active pores in the pore system [5]. Several theories for freeze-thaw processes in AAC have been established.

6 Possible degradation mechanisms in plastered AAC

6.1 General

Theories for the deterioration process in plasters may be based on the descriptions of agents in the CIB W80/RILEM 140-PSL report [2] and experiences of the behaviour of different AAC systems.

6.2 Chemical degradation in AAC

The moisture content in AAC materials depends on many environmental factors besides the climate, e.g. the type of plaster. Since the knowledge of moisture conditions is important for assessing the possible decomposition by chemical attacks, the critical moisture content should be determined for the effect of e.g. sulphur dioxide solutions, forming sulphurous acids, which are known to lead to a slow decomposition of AAC. Carbon dioxide gas in solution with water also forms carbonic acid which is a slight acid solution which dissolves calcium carbonate. The synergistic effect of different combinations of e.g. these agents to AAC and plaster systems are not fully known and should therefore systematically be studied in the future. Spicker has studied the chemical resistance of AAC to alkaline and acid solutions and found that AAC has limited or little resistance to weak acids [6]. Furthermore, the need for recording degradation over long periods is also pointed out.

The process of carbonation is not quite explained for the entire range of moisture conditions in AAC. Thus, the reaction rate has been observed to be slow both in dry and saturated materials [1]. This turns to the thought that there might possibly be an increased rate of carbonation in the external surface layer and / or in the crack surfaces due to a certain critical moisture content. In the inspections, the observed moisture content related to cracks has been higher in organic plaster systems compared to inorganic systems which also makes the carbonation rate in crack surfaces interesting to study more closely.

6.3 Degradation in inorganic plaster systems

The degradation in inorganic systems may be caused by chemical or physical incompatibility between mortars and AAC materials. These cases are known and should, however, be avoided by proper specifications in design of the systems.

The long term degradation of inorganic systems are likely to originate from leaching procedures, in the plaster as well as in the AAC, with water as the main solvent. The leaching process causes gradually degradation of the properties in the system as well as a change of the composition in the matrixes of the materials. The rate of the leaching processes in walls very much depends on the moisture conditions. In areas affected with a moderate level of driving rain the rate of degradation are probably slow due to short moist state periods but signs of degradation should possible be more easily recognized in the crack systems there moisture migration are more intensive.

6.4 Degradation mechanisms in organic plaster systems

Organic plasters based on acrylic resin are affected by UV-radiation and thermal variations. Chalking, fading and embrittlement by chain scission are known as visible and mechanical signs of ageing for these systems. Degradation by these factors can be assumed to affect the moisture protection properties of the plaster. Cracks noticed in this inspection have also been found to be more apparent in organic compared to inorganic systems. The formation of the first crack in the system may be caused either in the plaster or in the AAC material. Cracks starting in the plaster are likely depending on degradation of the plaster itself causing embrittlement and fatigue due to movements caused by variation in moisture content and temperature. Cracks starting in the AAC material cause the same increased water uptake and accelerated degradation in organic plaster systems. Cracks starting in the AAC material may be caused by many degradation agents, e.g. mechanical as well as chemical ones. The frequency, amplitude and duration of the moisture content to a certain critical level may be a basic assumption in forming cracks. Cracks propagate due to the local stress situation over the cracks as described in [7]. Agents forming the stresses may be caused by e.g. thermal and moisture actions.

The negative effect of cracks on the moisture balance of organic plaster systems applied to AAC has been shown by Sandin [8]. Cracks give the effect of increase in water uptake and are also followed by increase in movements from wetting and drying out procedures which secondary will cause more severe cracks. Then the water transport is relatively much higher through cracks than through the surface; the importance of water penetration in cracks may also be essential for degradation by leaching in surrounding materials. Water available in the crack system absorbs into the AAC material with a possible increase in the process of leaching and leachate transports caused by acid rain or dissolved pollutants. Cracks originating from carbonation should give the same latter process of deterioration in the AAC material.

6.5 Degradation by freezing

Theories for freeze mechanisms and determination of the critical moisture content in AAC for freeze damages are earlier established and referred to in several articles. Severe freeze damages are considered to occur when at least the micro and macro capillary system has been filled with water which corresponds to a moisture content of 44 % by volume. Above that moisture content an expansion in specimens have been measured and specimens with less saturation have shown even more contraction than expected from the temperature [9]. Another earlier source states that micro cracks in the structure of MC occur already at 60 - 70 % by weight (ca. 25 - 35 % by volume)

[10]. In the capillary pore system water is liquid at temperatures considerable below zero and therefore freezing starts in adsorbed water to surfaces of air pores or water filled small air pores forming a pressure in the system. When the average pressure in the matrix becomes higher than the tensile strength cracking will occur.

The lowest critical moisture content at which freeze damages may be detected in a micro scale is not yet defined. Fatigue and a succsessive degradation by freeze-thaw cycles at a rather low moisture content may be a possible degradation mechanism.

The difficulties to fill enough air pores in AAC to cause deterioration by freezing is well known, but a surface considerable frozen below zero and normally saturated may increase the moisture content in a following thaw period if ice in the pore system is melting in the outer parts and suction of melted water is prevented further inwards by a still frozen area. If the surface is covered by a film of water, melting ice will probably cause a suction in the pore system due to decrease in volume which will give a possibility for a higher degree of saturation. By these reasons a thin layer of MC probably will reach the critical saturation needed for freeze damages by scaling.

References:

1. RILEM Recommended Practise. *Autoclaved Aerated Concrete - Properties, Testing and Design.* 3.7 Durability. E&FN SPON, Chapman & Hall.
2. Haugenrud, *S.* E. *Environmental Characterisation including Equipment for Monitoring.* CIB W80/RILEM140-PSL, Subgroup 2 Report. Norwegian Institute for Air Research. Kjeller, Norway.
3. *Fukthandboken fig* 93.4, AB Svensk Byggtjanst, Solna. pp. 502.
4. Research report from studies by Gran, J.of micro pores in acrylic paint by scanning electron microscopy reported at a PhD course in Moisture Mechanics at the Royal Institute of Technology, Stockholm (1995).
5. Tada, S. Nakano, S., Microstructural Approach to properties of moist cellular concrete. Developments in Civil Engineering, *6. Autoclaved Aerated Con crete,Moisture and Properties.* Elsevier Scientific Publishing Company, 1983 Amsterdam - Netherlands. pp. 7 l-87.
6. Spicker, G. Chemical resistance of AAC. *Advances in Autoclaved Aerated Concrete,* . Wittman (ed.), 1992 Balkema, Rotterdam. pp. 165-170.
7. Zhou, W., Feng, N., Yan, G. Fracture energy experiments of AAC and its fractal analysis. *Advances in Autoclaved Aerated Concrete.* Wittman (ed.), 1992 Balkema, Rotterdam. pp. 135-140.
8. Sandin, K., The effect of the rendering on the moisture balance of the facade. *Autoclaved Aerated Concrete, Moisture and Properties.* Elsevier Scientific Publishing Company, 1983 Amsterdam - Netherlands. pp. 91-100.
9. Tada, S., Pore structure and moisture characteristics of porous inorganic building materials. *Advances in Autoclaved Aerated Concrete.* Wittman (ed.), 1992 Balkema, Rotterdam. pp. 53-63.
10. Roulet, C.-A., Expansion of Aerated Concrete due to frost - Determination of critical saturation. *Autoclaved Aerated Concrete, Moisture and Properties.* El sevier Scientific Publishing Company, 1983 Amsterdam - Netherlands. pp. 157-169.

Prediction of Durability for Performance-based Codes

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Abstract

New Zealand has had a performance based building code [1] for four years. The code superseded a prescriptive building system which effectively defined in detail how houses and low rise buildings should be built. The code sets out required performance levels in 35 areas which must be achieved in order for a building consent to be issued. These areas include structural design, weatherproofing, energy efficiency, plumbing and durability. The durability clause differs from the others in that it contains specific default minimum service lives for buildings and their components. The durability provisions apply to any part of a building which is fulfilling another code requirement (eg. structural stability), but do not cover aesthetic considerations.

Acceptable solutions and verification methods have been developed for most parts of the code which specify ways of meeting the building code or ways of establishing compliance through test or calculation. In the durability area however, methodologies and test procedures for predicting service life are still the subject of intensive research. Despite many hundreds of test methods published in reports and Standards, few accurate predictive techniques are available. As a consequence, the verification method for the durability clause provides guidance on the ways in which a durability assessment should be carried out rather than referencing test methods. This approach is also seen in the draft documents produced by the ISO TC 59 "Building Construction" subcommittee SC3 Working Group 9 looking at service life prediction methods. The New Zealand experience shows that while specific test methodologies which would enable durability predictions to be made for a wide range of materials would be preferred by industry, continued development and refinement of guidance documents such as those produced by TC59, offer the most realistic chance of improving service life prediction within the building industry.
Keywords: durability, performance, codes, prediction, test methods

1 Introduction

Ensuring that buildings have an appropriate service life has always been an important aspect of building design and maintenance and regulation. In New Zealand, traditional building regulations were based around standards produced by the national standards body. These regulations were adopted and amended by each local city and town council as they saw fit. Durability was implicitly recognised through tight adherence to prescriptive standards and limited availability of alternative designs and materials unless "approved by the engineer". These standards specified materials and construction methods which were designed to produce buildings with an undefined but acceptable life.

In 1992, the New Zealand Building Code (NZBC) [2] was introduced. The New Zealand Building Code is a performance-based building code which replaced the previous regulations and centralised the development and administration of building regulations. The rationale for building regulation reform was to simplify and to reduce the cost of building control. The basic tenets of the New Zealand Building Code are health and safety, with some consideration also for protection of neighbouring properties, the safety of fire-fighting personnel and energy efficiency. Aesthetics, quality and amenity issues, unless related to health and safety, are not considered. The NZBC contains 35 clauses defining building performance requirements. The NZBC is a performance based code rather than a prescriptive code. This means that it specifies performance levels which must be achieved in a building rather than specifying how to build the building and what materials to use. There is one exception to this philosophy, the durability clause (NZBC B2), sets default lifetimes for buildings and their parts. The reasoning behind this is that without some provision for ensuring that a building continues to meet the performance requirements, the durability of buildings would be set by market forces. Since a significant proportion of building owners can be expected to have little expertise in assessing materials and system performance, a minimum degree of consumer protection was considered appropriate.

2 NZBC B2 Durability

B2 effectively demands, that materials or components required to meet a performance level specified in any other NZBC clause, must continue to meet that performance level with normal maintenance for a stated time. Typical examples are; elements contributing to structural stability, weather-tightness, insulation, acoustics and fire resistance. The durability required is defined by default as 50 years for items; contributing to structural stability or, that are difficult to access or replace or, where failure would not be detected during normal use and maintenance. Elements which are moderately difficult to access and replace and where failure would be detected during normal maintenance, have a 15 year durability requirement. The remaining categories have a 5 year requirement.

Alternative building lifetimes can be specified at the building consent stage. For example, with some agricultural buildings a 15 year life may be appropriate. In these cases the building would be subject to a demolition order after the 15 year period unless appropriate reports where provided to show that it would continue to meet New Zealand Building Code requirements. With other structures, such as hospitals or bridges, a 100 year or more service life might be specified. In these cases this becomes a matter of specification and contract between the client and the design/construction companies.

3 NZBC compliance

Prior to the start of construction of any building, a building consent must be obtained from the local territorial authority. Before issuing the consent, the authority must have reasonable grounds to believe that the building as planned would meet the NZBC. While the New Zealand Building Code allows for innovation, it was recognised that many buildings would be constructed along traditional lines. To assist with this process "Approved Documents" were also published with the NZBC. These include "Verification methods" and "Acceptable Solutions". These documents set out methodologies which allow builders and designers to show approving bodies that they have met the performance requirements of the New Zealand Building Code. The approved documents are largely based on traditional building standards which have proved largely satisfactory over a long period of time. B2 Durability contains both a Verification Method (B2/VM1) and an Acceptable Solution (B2/AS1). B2/VM1 includes a statement to the effect that materials and building elements complying with a publication referenced in the Approved Documents are, subject to their appropriate use for the conditions likely to prevail in the specific building, deemed to satisfy the durability performance. This means that materials listed in an acceptable solution for B1 Structural Stability, will under the appropriate usage conditions satisfy B2. Only recently has B2/AS1 referenced specific standards setting out materials and their uses which are deemed to satisfy B2. These are NZS 3602 [3] which covers the selection of timber and wood-based products in building, and NZS 3101 [4] which covers the design of concrete structures. These two documents are prescriptive standards which have been developed from many years of research and actual service history in New Zealand. B2/VM1 provides generic guidance on how to assess the durability of materials, but does not provide specific advice for any particular class of material.

4 Assessment of durability

One of the main criticisms of NZBC B2 Durability by industry, is the lack of detail in the Approved Documents. Manufacturers' frequently want to assess the durability of a new material or system or, may be using a conventional material in a new application. They find the lack of a list of specific test methods which can be carried out on a product which will give them a durability rating of 5, 15 or 50 years frustrating. Those involved in materials testing will appreciate the difficulties inherent in such a simplistic approach. There are thousands of test methods available covering almost every material and application imaginable. Many of these tests are designed to show compliance of new product with a performance standard. Others involve some form of accelerated ageing such as; heat, wet/dry, freeze/thaw or UV exposure. Others compare performance to historically durable reference materials. Relatively few tests allow the prediction of durability to the precise levels that end users would like. Even if such tests are available, they often do not take into consideration issues relating to the usage of a material on each specific building (eg. macro and micro climates, materials interactions, usage intensity etc).

Some standards have been developed which instead of prescribing a set testing regime, give guidance on how to develop test procedures. ASTM E632 [5] is a good example which sets out a process for devising accelerated test methods. Lewry and Crewdson [6] discuss some of the issues involved in devising test procedures and relating these to real applications. Other standards and documents have been produced which take a wider view than testing and focus on the process of determining service lives for buildings and components. CIB and RILEM committee RILEM 140-TSL/CIB W80 committee has produced publications [7- 11] covering both service life prediction and the gathering of data for use in service life prediction. The British Standards Institution published BS 7543 [12] and the Architectural Institute of Japan a guide [13] both providing guidance on service life planning. Much of the previous work on service life prediction is being used in the development of ISO standards on service life planning. ISO/TC59/SC14 (previously TC59/SC3/WG9) currently has a draft standard on service life prediction methods in development [14]. Lacasse and Vanier [15] review work in this area in a paper presented at the most recent "Durability of Building Materials and Components" conference.

The approach taken in the durability verification method VM1 is to provide guidance on the principles involved in durability assessments. Three approaches are outlined:

- history of performance
- lab testing
- looking at the performance of similar products

4.1 History of performance

B2/VM1 recognises that a successful history of performance is recognised as the most reliable method of evaluating whether a product will be durable in any given application. Even if the period that the material has been used for is less than that required by NZBC B2, valuable information can still be obtained. A number factors are raised which need to be considered when assessing the history of performance of a material.

4.1.1 Climate

For products used on the exterior of a building the general climate is the main factor. General climatic influences are described but no data is provided on degradation agents in contrast to BS 7543 which includes air temperature maps and driving rain indices [12]. VM1 emphasises the need to ensure that the performance history and usage must be representative of the proposed new usage. This is particularly relevant where materials are imported from other countries because differences in climatic conditions and building practices can result in significant differences in durability.

4.1.2 Microclimate

General climatic factors can usually be assessed with the aid of meteorological records and local knowledge. However, building details and surrounding topography and vegetation create a number of localised micro-environments particular to each building. These micro-environments can have a major influence on materials performance. Some common examples are, the sheltered corrosion effects on under roof eaves, brick veneer cavities and sub-floor spaces. The sheltered corrosion effect results when parts of a building are sheltered from direct rain washing, but open to wind blown salt and dirt. The accumulation of salt and dirt causes rapid corrosion of metallic components unless they are regularly washed. Recent reports of failures of brick ties in masonry veneer cavities have also raised concerns that insufficient data is available on this microclimate [16].

4.1.3 Materials Interactions

- Individual materials that may be largely inert and durable by themselves, can, when in contact with other materials, degrade quite rapidly. This means that the specific use in building systems should be assessed as well the durability of each individual building material in question.

4.1.4 Changes in Formulation

It is very common for the formulation of a product to change over time. Changes may be made to improve properties, reduce costs, utilise new raw materials sources, or comply with health and environmental regulations. Whatever the reason, it is necessary to evaluate what the likely effect of any changes will have on new products compared to those used in the past. Major changes (eg. changing the resin type in adhesive) will make the past history of performance effectively irrelevant and the product will need to be evaluated as new. The effect of minor changes may be able to be accounted for by expert evaluation and or laboratory testing to confirm the relevance of previous formulations.

4.1.4 Degree of Degradation

New Zealand Building Code B2 requires that "elements and buildings must carry out their intended function for the life of the building. Simply showing that a product has survived for 20 years does not necessarily prove that it will still carry out its intended function for 50 or even 20 years. In obvious applications such as claddings, it will generally be easy to determine if a failure (ie, leakage, impact damage or wind damage) has occurred. For structural or fire applications, the design loading event may not have occurred over the history to date, and hence an appearance of soundness may not equate to adequate retention of physical properties to meet the original design loads. Retrieving samples from buildings and testing to establish whether deterioration has occurred and the nature of any deterioration, is highly recommended when assessing durability. This can give clues to the mechanism of degradation and also allow estimates of retained properties at the required lifetime.

4.1.5 Usage Intensity

Usage intensity refers to items (often mechanical hardware) which undergo some form of wearing action during use. One example would be closers on fire doors. The frequency of opening of the door over the life of the building will have a significant effect on the wear rate of the closer and the service life and maintenance requirements will vary accordingly. Usage intensity is most important in institutional, commercial and industrial buildings but may also be a factor in domestic housing (eg. specifying deck membranes where foot traffic occurs).

4.2 Laboratory Testing

In the event of a service history not being available, the only option available may be to carry out testing. The most reliable testing method is to set up natural weathering trials using the materials in question and attempting to simulate the actual exposure conditions as closely as possible. One of the drawbacks with this technique is that it can take a very long time to see any results. Manufacturers introducing products usually cannot wait more than 6-12 months so accelerated techniques then have to be employed. The key point in designing or assessing a "so called" durability test, is whether the test accurately reproduces the degradation mechanisms that take place in service. For this reason B2/VM1 requires expert interpretation of accelerated laboratory test results when used in determining likely service life.

5 Practical issues resulting from implementation NZBC B2

Acceptable solutions are intended to provide methods of construction which will meet the NZBC over a wide range of locations, building types and usages. As such, they are usually robust and provide solutions which may be very conservative in some applications. In most acceptable solutions, a material is selected from a table or list of options, or if it can be shown to meet set performance criteria. In contrast, when specifically designing a building, the opportunity is available to tailor each component to achieve the desired durability/cost/maintenance balance. In this case, durability assessments are just one source of information which can be used by the designer/engineer. Rather than a simple pass/fail scenario, the information required is what degree of degradation is likely to occur, how extensive will the degradation be over the building and what effect on physical properties will the degradation have. The decision on acceptability can then be made by the designer in light of the information provided by the durability assessment/testing and the other design parameters set by the client's requirements and the appropriate loading conditions. An unresolved issue associated with the NZBC is that it does not state what an acceptable level of risk is. Since it is impossible to completely eliminate defects in a construction process, the level of risk is never zero. Historically, the level of defects which can be tolerated is set largely by the market or by society through codes and standards and tends to be very small. The actual value being a compromise between quality or safety and cost. NZBC B2 Durability does not provide any guidance of what level of risk is acceptable in assessing durability. However, since the purpose of B2 is to ensure that the other NZBC functional requirements are maintained over the life of the building, some guidance on the degree of deterioration allowed can be found in the other functional requirements. For example, concepts of reliability are covered in the B1 Structure verification method B1/VM1. Engineers typically design fixings using a 5 percentile value for resistance. This means that there is a 95% probability that the resistance of any particular fixing will exceed the design parameters and that the mean of all the fixings will be well above the design level. Similarly, the design loads are set at a level which ensures a low probability of them being exceeded over the life of the building. In this context, one argument is that that the conservatism associated with the terminology "reasonable evidence" is in place and need not be duplicated in a durability assessment. However, the levels of risk that can be inferred from B1/VM1 are not necessarily minimum risk levels, but they have been deemed acceptable. Work being carried out in Australia on timber durability, is attempting to bring engineering concepts such as reliability theory into durability design [17]. This approach requires quantification of agents causing degradation for each material as well as models which can predict degradation under a range on environmental conditions. Work is being carried out in New Zealand this areas [18].

6 Conclusions

While B2/VM1 provides general guidelines for assessing durability, and additional information is available in documents referenced previously [5-14], there are few organisations with sufficient expertise and resources in New Zealand able to carry out assessments of materials durability and service life prediction. This becomes particularly evident when new building systems utilising a range of traditional materials (steel, timber, concrete) are combined with polymeric materials such as plastics and resins. As well as materials expertise; structural, weathertightness, thermal, fire and buildability issues need to be worked through. The construction industry has placed a good deal of reliance on fitness-for-purpose system appraisals similar to the European Agrément system.

From an industry perspective, the realisation of the innovation and potential economic benefits offered by a performance-based building code will be enhanced by the development of improved acceptable solutions for B2 Durability. Improvements need to be targeted at three levels;

1. standards providing guidance on durability assessments and service life prediction
2. test methods for individual materials and systems
3. development of reliability-based models

The international effort going into the work of ISO/TC59/SC14, offers the potential of a unified approach being adopted for the process of assessing durability and service life for buildings and their components. A common methodology will assist those involved in assessing information presented as part of the compliance process particularly when material from another country is presented.

Improved predictive test methods for individual materials and their applications, continue to be developed by manufacturers, researchers and national standards bodies. These tests will eventually find their way into acceptable solutions when they become accepted by national standards bodies or major research organisations.

The incorporation of durability into the engineered design of buildings is still some distance away and requires considerable background work in each country as well as cooperative efforts within the international community. The eventual availability of reliability-based service life prediction techniques will mean explicit durability provisions in performance-based codes are likely to become more widely accepted.

8 References

[1] New Zealand Government. (1991) *The Building Act*. Wellington

[2] Building Industry Authority. (1992) *The New Zealand Building Code Handbook and Approved Documents,* Standards New Zealand, Wellington

[3] Standards Association of New Zealand. (1995) *Code of practice for specification for timber and wood-based products in building.* NZS 3602. Wellington

[4] Standards Association of New Zealand (1995) *Code of practice for the design of concrete structures*. NZS 3101. Wellington

ASTM E632. American Society for Testing and Materials. (1982) *Standard practice for developing accelerated tests to aid prediction of the service life of building components and materials*. ASTM Annual book of standards, Vol 14.02. Philadelphia

[6] Lewry, A.J. and Crewdon, L.F.E. (1994). *Approaches to testing the durability of materials used in the construction and maintenance of buildings*. Construction and Building Materials. Vol. 8 No. 4.

[7] CIB. *Prediction of Service Life of Building Materials and Components*. CIB Publication 96 L.W. Masters and E. Brandt (ed.)

[8] Masters, L.W CIB (1986) *Prediction of Service Life of Building Materials and Components*. Matériaux et Constructions/Materials and Structures, Volume 19, No. 114.

[9] Masters, L. W. and Brandt E. (1989) *Systematic Methodology for Service Life Prediction of Building Materials and Components*. Matériaux et Constructions/Materials and Structures, Volume 22, No. 131.

[10]. CIB. *Feedback from Practice of Durability Data. Inspection of Buildings.* CIB Publication 127 C. Sjöström and E. Brandt

[11] CIB. (1990) *Feedback from Practice of Durability Data. Examples of Field Investigation.* CIB Publication 128. Brandt E. (ed.)

[12] British Standards Institution. (1992) *Guide to the durability of buildings and building elements, products and components.* BSI 7543. London.

[13] Architectural Institute of Japan. (1993) *The English language edition of the principal guide for service life planning of buildings*.

[14] International Standards Organisation. (1997) *Service life prediction methods*. Working Document to ISO TC59/SC3/WG9. ISO/WD 15686-2.2.

[15] Lacasse, M.A. and Vanier, D.J. (1996) *A review of service life and durability issues*. In Durability of Building Materials and Components 7. Ed. Christor Sjöström. E & F N Spon.

[16] Cole, I. S. (1993) *Newcastle earthquake and wall cavity corrosion : implications for the rest of Australia*. Corrosion Australasia. Vol. 18. No. 3

[17] Leicester, R. H. (1995) *Project proposal -Design for durability of structures*. Appendix B in: Proceedings of Timber Durability design Workshop. Forest and Wood Products Research and Development Association and National Association of Forest Industries. July . Melbourne.

[18] Kane, C. D. (1996) *Atmospheric corrosion survey of New Zealand - six year results*. IPENZ Transactions. Vol 23. No. 1/EMCh. Wellington.

Development and validation of the Wetcorr Inwood method

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Abstract
The present report summarises activities in relation to the EU-project ENV4-CT95-0110 Wood-Assess. One part of that EU project focuses on methods for measuring the surface time of wetness and the resulting moisture content inside wood on a continuous basis. In this report we present measurements of the Wetcorr currents, from both traditional surface moisture sensors and Inwood sensors, on selected positions at some objects chosen in the project. The traditional Wetcorr sensors are used to estimate the time of wetness. The currents from the Inwood sensors give the corresponding moisture content inside the wood. The measurements presented are from two of the objects in the project and from all of the facades.
Keywords: Wetcorr, Moisture content, Time of Wetness, Microclimate, Wood

1 Introduction

The present report summarises the results of work package two in the EU-project "Wood-Assess". The full name of the project is "System and methods for assessing conservation state and environmental risks for outer wooden parts of cultural buildings". The second work package in the RTD-project has the following objectives:

Develop and validate methods for measuring:
1. continuous surface time of wetness (TOW) and corresponding moisture content inside wood (INWOOD)
2. integrative damage to wood.

In this report we present results relating to the first of these two objectives. The following main issues were addressed as part of work package two:
- Develop a robust electrode system for measuring the long term moisture content of wood under field conditions.
- Theoretical and practical investigations of the measuring technique in terms of electrode geometry and configuration, moisture content and gradients, differences between WETCORR and more conventional techniques.
- Calibration of WETCORR INWOOD in climate cabinet using three different wood species.

The second of these points has already been described in another report [1]. The present report is in principle divided into two different parts. The first part, given in sectors 2-4, describes the measuring system, especially focusing on the new sensor technique; WETCORR INWOOD. It also describes the calibration procedure used for translating the measured currents in the wood into a corresponding moisture content. The second part, presented in sectors 5-6, describes some of the different objects where the field measurements are performed and results from these measurements. It also includes a brief discussion of how the measured currents are influenced by the positions chosen for the measurements.

2 Electrode system

The use of the WETCORR measuring system for long-term monitoring of moisture content of exterior wood requires certain considerations to be made in order to obtain reliable and consistent data. The electrodes should be easy to install and should perform well throughout the measurement period without any need for adjustments or maintenance.

Since there is some concern about nail electrodes not maintaining electric contact with the wood with time because of moisture induced movements and relaxation of the wood, it was decided that some kind of screw should be employed. A suitable screw in austenitic stainless steel (SS2347, 17.5Cr-11Ni-2.3Mo) was used which is readily available from hardware stores. The original screw has a flat, blade-like head through which there is a hole used for mounting the connector for the leads from the measuring equipment. The connector is made up of a crimp red sleeve terminal eyelet attached to the screw with a blind nut. The stem and part of the threaded area of the screw is protected by heat-shrinkable tubing containing an adhesive lining designed to provide a moisture proof encapsulation. In order to avoid penetration of moisture along the screw/wood interface, a thin layer of one-component polyurethane glue is applied circumferentially on the stem of the screw close to the wood surface. Holes for the electrodes are pre-drilled using a 6.5 mm drill-bit and stopper which ensures a constant depth of 12 mm. The distance between the electrode-pairs is not critical but has been chosen to 30 mm for all installations made in the field as well as in the lab tests. The leads from the WETCORR equipment are connected to the electrodes with a crimp tool. All parts of the electrode including the connector are protected by the same type of heat-shrinkable tubing as used for the actual electrode. Finally, the electrodes and leads are taped with white plastic tape to minimise pick-up of heat from radiation during sunny days.

3 Theoretical and practical aspects of wood moisture measurements

The WETCORR system [2] in its present version was not developed specifically to be used as a wood moisture monitor. Since all of the four moisture channels in each sensor adapter have a common ground, the paths for the recorded currents cannot easily be separated unless the electrode pairs are galvanically isolated from each other. Unfortunately, this is not the case for building facades. Consequently, if more than one INWOOD sensor is hooked up to the sensor adapter the readings obtained are generally not representative of the MC in the location where the electrodes are mounted. In the short term these difficulties can be overcome simply by not connecting more than one electrode pair per sensor adapter at a time. In the future, however, up-dated versions of the WETCORR system will most likely be designed with galvanically isolated moisture measurement channels.

Tests in the lab have been performed using multiple sensors and long distances between the electrodes of the same pair and between the pairs. It may be concluded that the channel interference ***cannot*** be avoided by long distances between the pairs. Refering to Figure 1, even the resistance between electrodes that are mounted at very long distances from each other is small compared with the resistance associated with the wood/electrode interface [3].

Re1 and Re2 are associated with the wood/electrode interface and Rw with the bulk resistance of wood. In the presence of moisture gradients, large differences would also be anticipated between Rel and Re2. The moisture reading results obtained are from the total resistance in the electric circuit. Consequently, the electrode that is situated in the driest part of the wood will give the dominating contribution to the moisture reading.

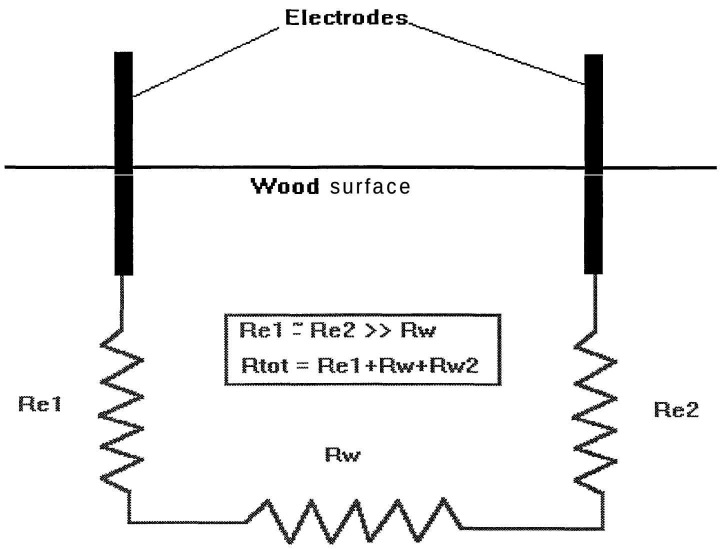

Figure 1. Schematic showing the distribution of electric resistance across two wood moisture electrodes (after Ref [3]).

The high resistance associated with the wood/electrode interface will prevail as long as the surface area of the electrode is small compared with the minimum cross-sectional area of the wood anywhere between the two electrodes. This effect arises as a result-of the propagation of the electric field between the point-like electrodes combined with the volume resistance of wood. From geometrical considerations the highest current density will occur close to the electrode surface which then causes a much higher voltage drop than in the bulk of the wood [1]. In general, this means that for measurements in wood with large cross-sections, the distance between the electrodes is of very little significance.

4 Calibration of WETCORR INWOOD under controlled conditions

The most common way of expressing moisture content of wood is as the percentage ratio of the weight of moisture to the weight of dry wood. Since most experience and all moisture related criteria for physical and biological aspects of wood are expressed in this way, the current measured with the WETCORR INWOOD system has to be translated into moisture content.

A 5 m long board measuring 8”x1½” in cross-section was dried from the green condition of 30 % Moisture Content (MC) to about 15% MC. The WETCORR INWOOD currents were correlated with the readings obtained with a Protimeter Timber-master, as shown in Figure 2. As these experiments were done in a room without temperature control a variation between 23 and 25°C was not possible to avoid. Still there is a fairly close fit of the data to a power function. Further tests have been performed to correlate the WETCORR INWOOD currents with the true moisture content established by weighing after exposure to various humidity and temperature conditions in a climate cabinet [4].

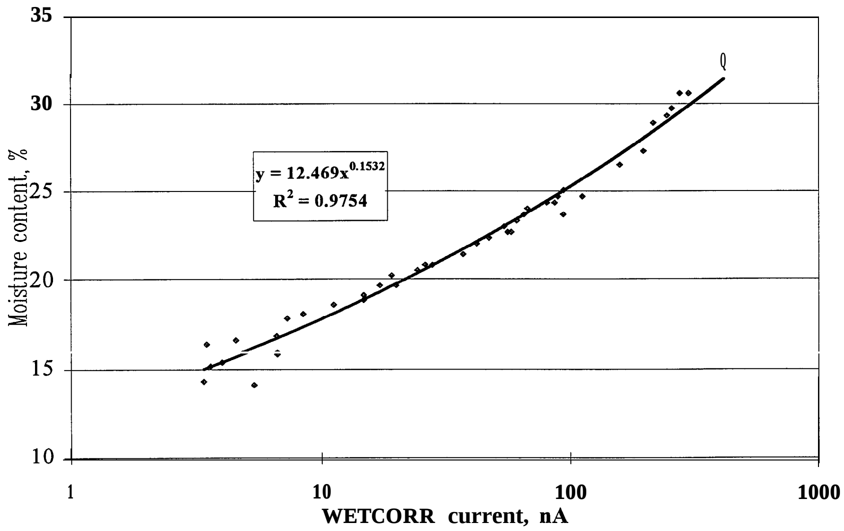

Figure 2. Moisture content according to Protimeter Timbermaster plotted against the WETCORR INWOOD current at 23-25°C.

The TOW is calculated using a current level of 1 0nA [5] and according to the calibration the MC is calculated using the formula given below [4]:

$$\log MC = A + B \log I + C/T + D\rho$$

where A, B, C and D are constants, I is the measured INWOOD current, T is the measured INWOOD temperature in degrees Kelvin and ρ is the dry density of the wood.

5 Description of the objects chosen

In the project, measurements are performed on four out of five objects. Below a short description of two of the measured objects together with their climatic situations are given.

The two objects presented in the report are both situated in Sweden. One house is in the town of Gävle, Berggrenska garden, and the other close to Waxholm, Norrkulla, which is north-east of Stockholm. Berggrenska garden is a log house construction with two floors and a basement. The house has dimensions 3 1.2 x 12.8m. The walls are cladded with wood and the roof is of a mansard type originally with tile but today it is covered with black painted steel sheet. The house was slightly rebuilt after the city fire in 1869 and the latest refurbishment of the house occurred in the mid 1980's. At that time the cladding was in some parts replaced and on the other parts, only repainted. The original roof was replaced in 1896 and then again in 1977. The wall cladding was also repainted in the summer of 1997, during the period when measurements were taken. The house is comprised of a main building and two wings which were erected at approximately the same time as the main building.

The climate in Gävle is urban coastal with cold winters. The house Norrkulla is a timber framed construction with exterior wood cladding. The building technique used is corner timbering where the logs of two adjoining walls are interlocked. Walls on the first floor are reinforced by vertical walling. The logs had dimensions of 150x200mm. The supporting structure of the roof is a Swedish roof truss lying on the timber framed walls and covered with roof tiles. The foundation consists of stones in each corner. The major difference in climatic situation compared to Gävle is that the house is not in an urban environment.

6 Results from measurements

The measurement methods for moisture are based on the NILU WETCORR measuring device. The existing gold sensors measure a surface current, which after calibration gives the surface time of wetness (TOW) [2]. The nail electrodes were developed into a new sensor application, WETCORR INWOOD, previously described. The measured currents in the wood after calibration give the moisture content in the wood [4]. In this report we present TOW and moisture content at certain positions chosen on the objects. As an example we present the different positions at Berggrenska garden in some detail, given in Table 1. The division into different categories and the numbering of facades, fields, boards etc. are explained in another report from the Wood-Assess project [6].

Table 1 Wetcorr installation "Berggrenska gården", location of sensors

Sensor adapter	Sensors	2nd category	Elements in the Categories 3rd category	4th category	5th category
01	WC 1.1*	facade 1.2	field 3	board 12	40 cm right side of window
	IW 1.2	facade 1.2	field 3	board 12	40 cm right side of window
	WC 1.3	facade 1.2	field 3	board 13	10 cm above counter batten
	IW 1.4*	facade 1.2	field 3	board 13	10 cm above counter batten
02	WC 2.1*	facade 1.2	field 9	board 1	a few cm above counter batten
	IW 2.2*	facade 1.2	field 9	board 1	a few cm above counter batten
	WC 2.3	facade 1.2	field 9	board 2	close to window
	IW 2.4	facade 1.2	field 9	board 2	close to window
03	WC 3.1*	facade 2.2	field 1	board 13	20 cm under counter batten
	IW 3.2 *	facade 2.2	field 1	board 5	20 cm under counter batten
	WC 3.3	facade 2.2	field 2	board 12	20 cm under counter batten
	IW 3.4	facade 2.2	field 2	board 4	20 cm under counter batten
04	WC 4.1*	facade 3.1	field 2	board 2	3 cm above skirting
	IW 4.2*	facade 3.1	field 2	board 2	3 cm above skirting
	WC 4.3	facade 3.1	window 2	window	under window 1-2
	IW 4.4	facade 3.1	window 2	window	under window 1-2
05	WC 5.1*	facade 3.1	field 8	board 9	20 cm above the skirting
	IW 5.2*	facade 3.1	field 8	board 10	20 cm above the skirting
	WC 5.3	facade 3.1	field 8	board 16	on the skirting
	IW 5.4	facade 3.1	field 8	board 17	on the skirting
06	WC 6.1	facade 3.2	window 9	board	window 4
	IW 6.2	facade 3.2	window 9	board	window 4
	WC 6.3*	facade 3.2	field 9	board 20	40 cm right side of window
	IW 6.4*	facade 3.2	field 9	board 19	40 cm right side f window
07	WC 7.1	facade 4.1	field 3	board 6	on the counter batten
	IW 7.2 *	facade 4.1	field 3	board 7	on the counter batten
	WC 7.3*	facade 4.2	field 3	board 7	50 cm under the counter batten
	IW 7.4	facade 4.2	field 3	board 7	50 cm under the counter batten

The measurement period for the investigated objects starts from the autumn of 1996 until the end of 1997. During that period the object Berggrenska garden has been repainted, June 1997, which gave us an opportunity to study the moisture content in wood before and after painting.

6.1 Berggrenska gården

For the Berggrenska garden house we present results from measurements in October to December for both 1996 and 1997. The major difference between the two years is that during the summer of 1997 the house was repainted. Figure 3 shows the Time Of Wetness (TOW) and the Moisture Content (MC) for one of the sensors.

We have not measured the INWOOD temperatures for all the sensors and not for the entire measuring period. The reason is simply that the INWOOD temperature sensors were not developed when the measurements started and we also had less than ten of them, some of which were used at Norrkulla, the other Swedish object in the project. In instance where we did not have INWOOD temperatures we used the WETCORR temperatures closest to the Inwood sensor. As can be seen from Figure 3 the first couple of weeks had no precipitation and the MC remained at the same level. With an increase in the TOW an immediate increase in MC occurred. Then there is a period of rather low TOW and during that period the MC is almost stable. A rather high TOW around 19-20/1 1 gives an increase in the MC once again. The MC level is now around 30% which is almost at the fibre saturation point. After, the MC slightly decreases, but the value reached at the end of the period in question is still very high.

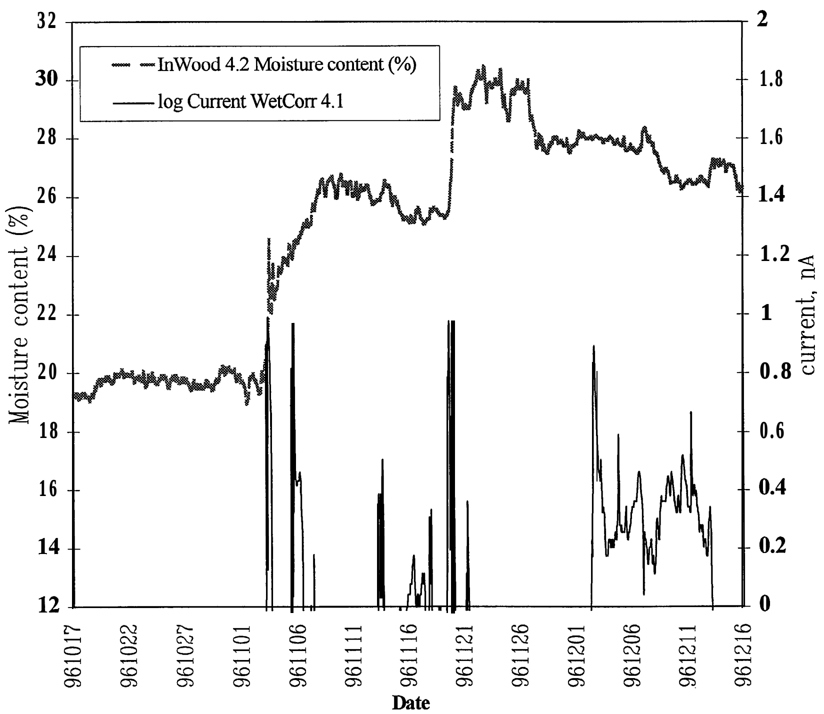

Figure 3. Moisture content (%) and Time of Wetness at SA04 on the north facade of Berggrenska gården October-December 1996

With the measured temperatures and currents we can calculate the MC's for all the sensors. In Figure 4 we give the TOW and the percent of time when the MC is above 20% and 25% for all the seven sensors (Table 1). As can be seen in Figure 4 the TOW between the autumn of the two years differ, with a much higher impact for SA02-SA05 in 1997 and for SA07 in 1996. The main difference between the two years regarding the precipitation is the main direction from where the rain came. In the autumn of 1996 most of the rain came from west or south-west and in the autumn of 1997 almost no rain at all came from those two directions.

If we observe the MC instead we find that the values of 1997 are significantly lower than for 1996 even for the SA's with the higher TOW in 1997. The main reason for the lower MC's for 1997 is the application of a new paint on the wood surface. The penetration of moisture into wood is lower with a fresh paint compared to an old one. We can also study the MC's from the different positions on the object. The different positions are given in Table 1. The results given in Figure 4 are based on one of the Wetcorr sensors and also one of the Inwood sensors, marked with a * in Table 1. If we study the sensors on the south facade, SA01 and SA02, we find that MC's over 20% are reached approximately 40% of the time while for SA02 some 15% of the time period MC's are even over 25%. The sensors SA01-02 are placed almost on the same height on the facade and they differ with 8-l Om with SA01 on the left and SA02 on the right part of the facade. There are at least two reasons for the higher levels reached at SA02, one is the distance to the counter batten which is shorter and the other is the more degraded paint and wood at SA02.

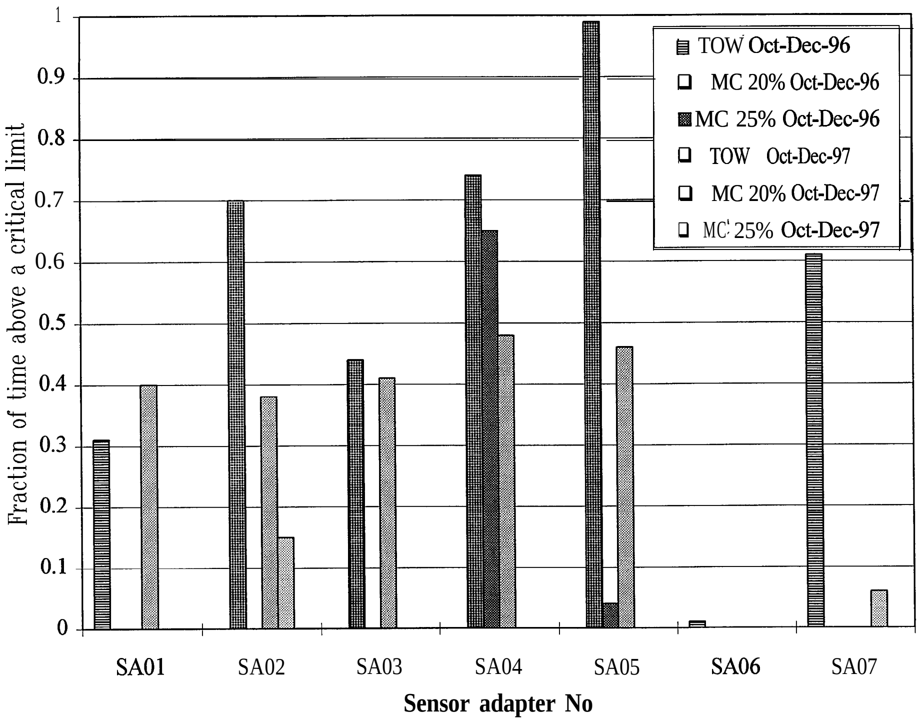

Figure 4. A comparison between the amount of Moisture Content over specified levels and Time of Wetness for seven positions at Berggrenska gården in the autumns of 1996 and 1997.

The MC for SA03 is of the same order as for SA01-02 even though the position on the house is different. SA03 is situated at the same level above the sea but not on the same level above ground. SA03 is much closer to the ground and also somewhat protected from sun by vegetation. SA04-06 are all situated on the north facade with the former two close to the ground are rather well protected from any kind of sunshine. SA06 on the other hand is situated in the middle of the facade and rather open but under eaves. The MC's for the three differ accordingly with a really high MC for SA04-05 and a low MC for SA06. It can also be seen on the wooden parts that the region close to SA04-05 is very much deteriorated while the region close to SA06 is in seemingly good condition. In the last case a rather high amount of rain reached that part of the facade were the sensor is placed, as can be seen from the TOW, even though a very low **MC** was still measured. The reason is that the sensor is situated on an unprotected part of the facade which implies a good possibility to dry out the surface moisture.

6.2 Norrkulla gård

Results from the measurements at Norrkulla gård for the period October 1997 to December 1997 is presented in Figure 5. The moisture content is high for all of the sensors, frequently near or above 20 %, except for Inwood sensor 5.4. The Inwood sensor 5.4 is located on the south side close to the east gable. The only other Inwood sensor located on the south facade is located on the west side of the facade and in a higher position.

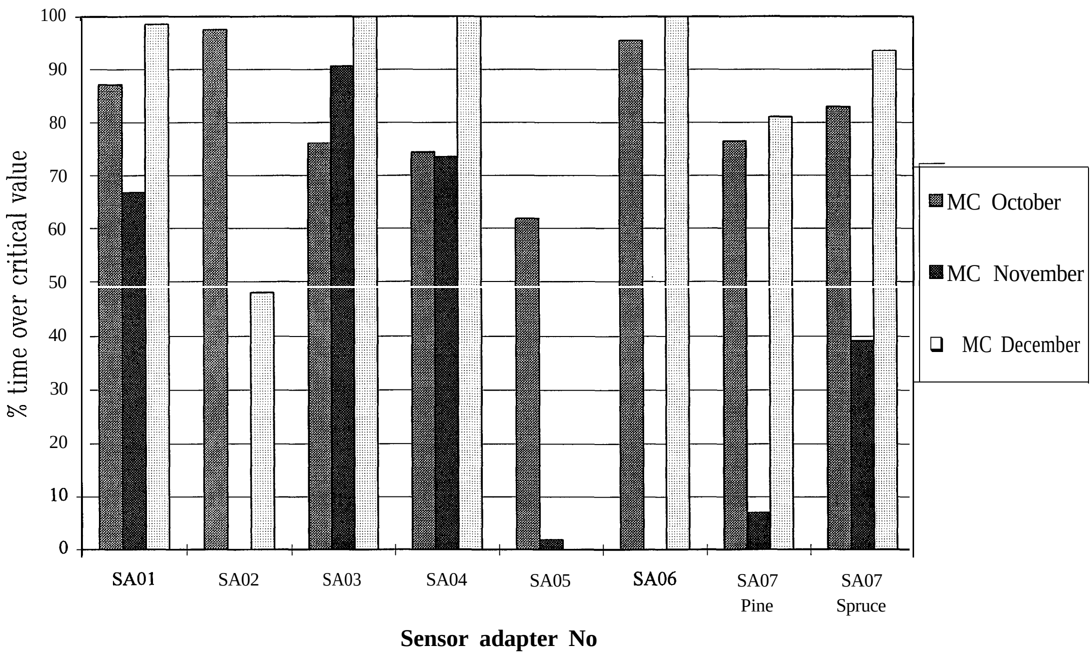

Figure 5. The results from the measurements showing the time in % when the Moisture content inside the wood is over 20% during October to December at Norrkulla gård

The reason for the difference in moisture content for the two Inwood sensors on the south facade is not clear from measurements of TOW at either position. A slightly lower TOW can be found at the position of Inwood sensor 5.4. The difference in TOW is, however, to small to explain the rather high difference in moisture content. We believe the difference instead can be found in the quality of the wood at both sensors. Sensors 7: 1 to 7:4 are applied on a rack with wood panels (spruce and pine) which is located about 20 m from the west facade. The sensors are exposed in a horizontal angle of 45 degrees facing south. The results show a rather high difference in moisture content for October and the difference is gradually decreasing for November and December. The difference is most likely due to the prehistory of the wood material and also to the overall quality of the wood samples.

7 Discussion

The measurements performed at the different objects show the potential of using both the WETCORR sensor and the new INWOOD sensor. The importance of positioning the sensors on to a facade is not fully studied in this project. The positions of the sensors are very important in order to predict, for instance, the service life of a wooden facade. For such service life estimations the climatic impact on the facades must be known or at least approximately known. The WETCORR and INWOOD sensors can be used for making models of the climatic impact by measuring the climatic impact on some facades and connecting measurements to local climatic data. Some work have been done in this field in the Wood-Assess project [7].

8 References

1. Grahn J (1997) Electrical measurement of moisture content in wood. Influence of specimen geometry and electrode configuration. M.Sc Thesis, *TRITA-BYMA 1997:6 E*, Royal Institute of Technology, Stockholm.
2. Henriksen J F, Haagenrud, S E and Store M (1992) Monitoring of the wetness impact on building by means of a new instrument for continuous recordings (EUREKA EU 615 EUROCARE WETCORR). *NILU REPORT A 7/92*.
3. W L James (1994) Fundamentals of hand held moisture meters: An outline. *Proc ASTM Hand Held Moisture Meter Workshop,* Madison, WI, 5 May 1993, pp 13-16
4. Norberg P (1998) Calibration of WETCORR INWOOD electrodes for measurement of wood moisture content. EU-project:ENV4-CT95-0 110, WOOD-ASSESS, *Wood-Assess Document No: WP2/4/KTH-BMG/1998-02-15*.
5. Elvedal U (1998) Calibration of WETCORR sensors and interpretation of field measurements. *NIL U TR 12/97*.
6. Veit J et al (1998) System and Methods for assessing the conservation state for the outer wooden parts of cultural buildings - Assessment Protocol. Paper submitted to *CIB World Building Congress 1998 Gävle, Sweden*
7. Henriksen J F et al (1998) Wood-Assess - Mapping of environmental risk factors on the macro, meso and micro scale. Paper submitted to *CIB World Building Congress 1998 Gävle, Sweden*

Wood-Assess – Mapping environmental risk factors on the macro local and micro scale

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Abstract
There are great differences in temperature and precipitation regimes in Europe, resulting in equally differences in the potential wood decay rates. This paper describes the work carried out in the EU project ENV4-CT95-0110 Wood-Assess to develop and validate methods and technologies for mapping and assessing environmental risk factors and areas to wooden buildings in macro, local and micro scale. Due to the very complicated nature of the degradation system for wood, very few quantitative dose-response functions exist to day. The assessment of risk factors has therefore one hand been based on calculating Scheffer's index from existing meteorological monthly data for chosen regions and to model the results into a geographical information system (GIS) based information system for regional prediction of wood rotting. The index has on the other hand been tested and linked to micro-environmental exposure by the use of WETCORR measurements. The WETCORR instrument has been used to map the temperature and time above critical moister in the micro-environment. The results indicate that the rotting process is more complicated that the Scheffer's index is able to explain and that that the duration and amount of precipitation must be taken into account. By using a WETCORR instrument these problems can be partly solved.
Keywords: wooden buildings, rotting, moisture, mapping of risk factors, geographical information system (GIS).

1 Background

The deterioration of wood structures is influenced by a large variety of factors. The most common and often the most serious damage on wood is the rotting process. To be active the fungi involved need sufficient water and the right temperature regime. Beside capillary absorption of water from the ground, the main water source for the fungi is the amount of rain fallen on the structure. Due to the climatic changes throughout Europe, there will also be changes in the risk for rotting across Europe. Since meteorological data for temperature and precipitation are measured and reported in all European countries, the idea of using existing data for the prediction of risk of rotting has been put forward. A well known equation for this prediction is Scheffer's Climatic Risk Index (CRI) [1].

$$CRI = \frac{\sum_{Jan.}^{Dec.}\left[(T-2)\,(D-3)\right]}{17}$$

T= monthly average temperature
D= average values for days with rain

A problem for assessing the rotting of wood is the observed local variation in the parameters through out a region and in the micro environment on a building. It is therefore necessary to do measurements both on a local scale as well as on the micro scale on the actual building.

In WOOD-ASSESS one of the tasks has been to compare CRI calculated at the nearest meteorological measuring site with CRI calculated T and D values obtained locally and the real time with wet surface on a building. To study these events the instrument NILU WETCORR has been used [2]. This instrument is specially designed for measuring the time of wetness on surfaces.

A second task has been to use available meteorological data and to model these data and CRI for rotting on a regional scale taking into consideration the topographic impact on the climatic parameters.

2 Field studies

To study changes in the wetness impact on local and micro scale field test sites were put up at four locations:

- Hjeltarstua, Maihaugen in Lillehammer Norway
- Berggrenska Gården, in Gävle, Sweden
- Norrkulla Garden in Stockholm, Sweden
- Alte Mange1 in Ebersbach, Germany

The principle of the set up is shown for Hjeltarstua in Figure 1.

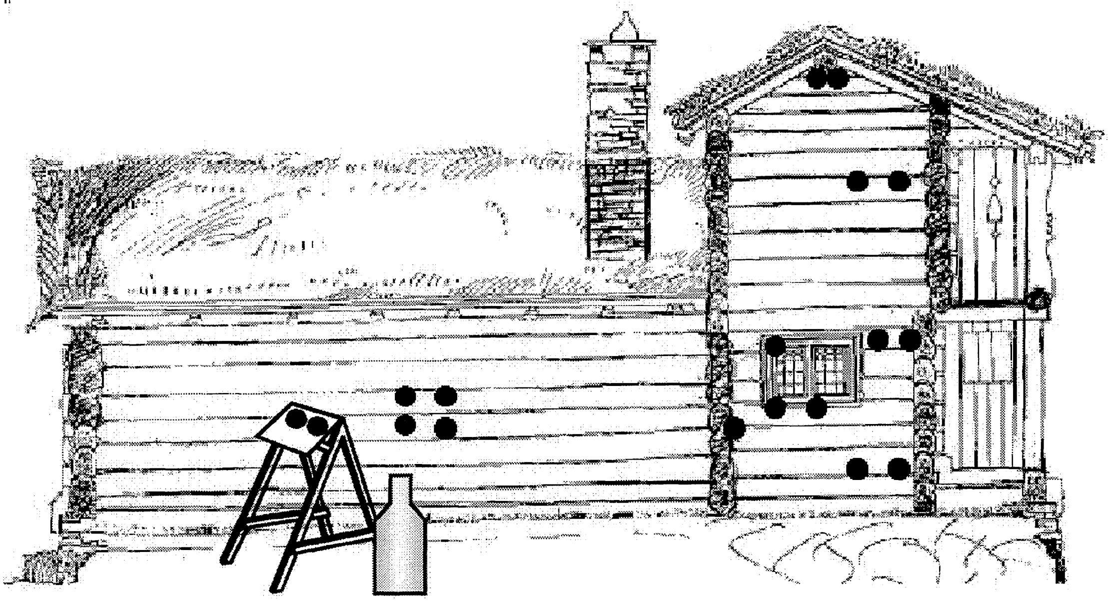

Fig. 1. The experimental set up for measuring the wetness impact on Hjeltarstua.

The local set up consists of a pluviograph for measuring the number of rain events. A test rack where four wood panels, two Norwegian spruce and two pine, were exposed to the climatic conditions facing south with an angle of 45°. A WETCORR instrument with one WETCORR sensor for measuring the real time with wet surface on the wood panels, two INWOOD sensors for measuring the moisture content inside the panels and one temperature sensor for the air temperature.

3 Results of wetness impact at different levels

3.1 From regional to local level

In this paper the results are illustrated by providing the results from the Norwegian site at Maihaugen. The nearest meteorological site Sætherengen is located approximately 0.5 km from the test rack but at a lower altitude. One complication for the comparison was that the local pluviograph had a precipitation sensitivity limit of 0.5 mm, whereas the meteorological authorities normally reports 0.1 mm. At Sætherengen 0.5 mm data were also available. In Figure 2 the monthly data for days with rain above 0.5 mm for Maihaugen and 0.1 and 0.5 mm for Sætherengen is presented. During the spring, autumn and winter months the-variation between monthly values were minor, only one to two days, while during summer the variation is much higher between the sites. In July there is also a large difference between 0.1 and 0.5 mm precipitation at the meteorological site. On a yearly basis the 0.5 mm daily values were 24% higher for the meteorological site than for Maihaugen. The pluviograph at Maihaugen recorded the rain events as change in the weight of the collector. Since the pluviograph was situated in the sun the uncertainty will be higher with smaller amounts of precipitation and warm weather due to evaporation. If we take away the months July, August and September from our calculation, the difference between the two sites drops to 6%.

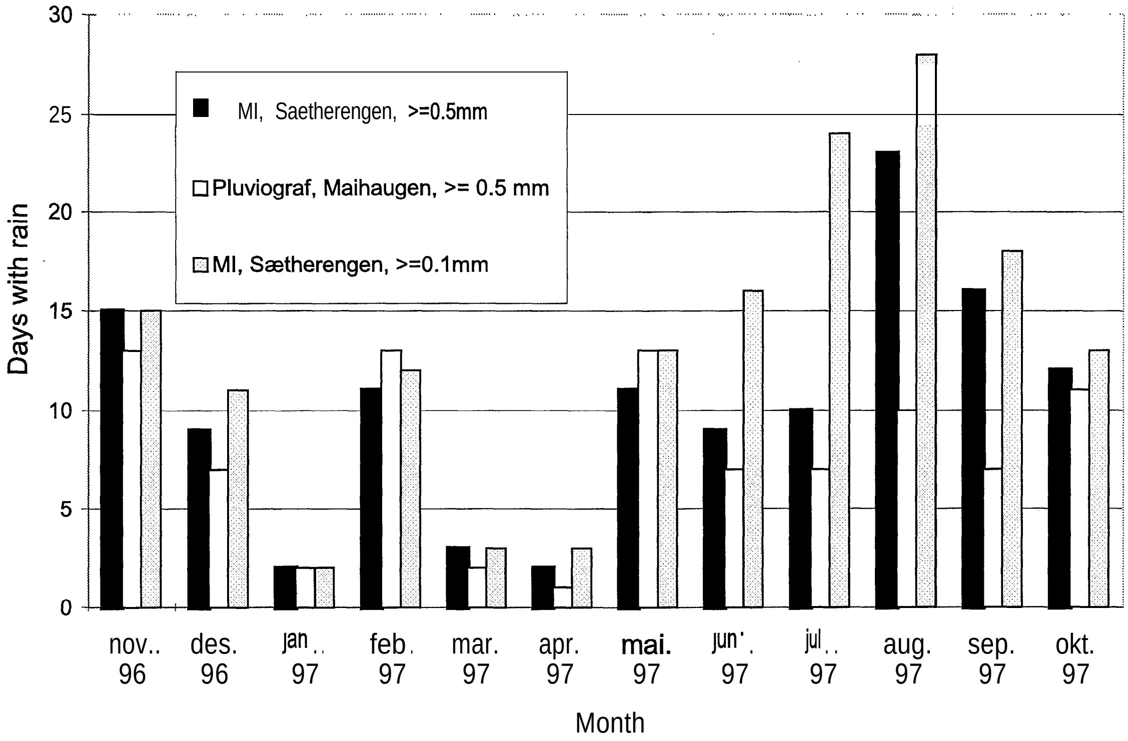

Fig. 2. The results of "days with rain" reported from Sætherengen and the pluviograph at Hjeltarstua, Maihaugen.

The difference between days with rain calculated with 0.5 mm and 0.1 mm was on a yearly basis 35 days or 28%. Most likely this percentage will be the same for Maihaugen. In Figure 3 the pluviograph data from Maihaugen is compared with the WETCORR results from the rack. Two different current limits for detection of surface wetness were used. At Maihaugen where the pollutant level is low, a current level of 15 nA gives a good indication of periods with rain. current limit 10 nA will also include other types with wet surface such as dew and gives a slightly higher value for the time with surface wetness. Days with rain over 0.5 mm recorded gave a lower number than days measured with the WETCORR instrument. However if we adjust for the uncertainty in the Summer results and add the corrections for the precipitation limit 0.1 mm, the WETCORR data and the pluviograph data will be close. A freely exposed WETCORR sensor will therefore give days with rain which are comparable with the pluviograph data.

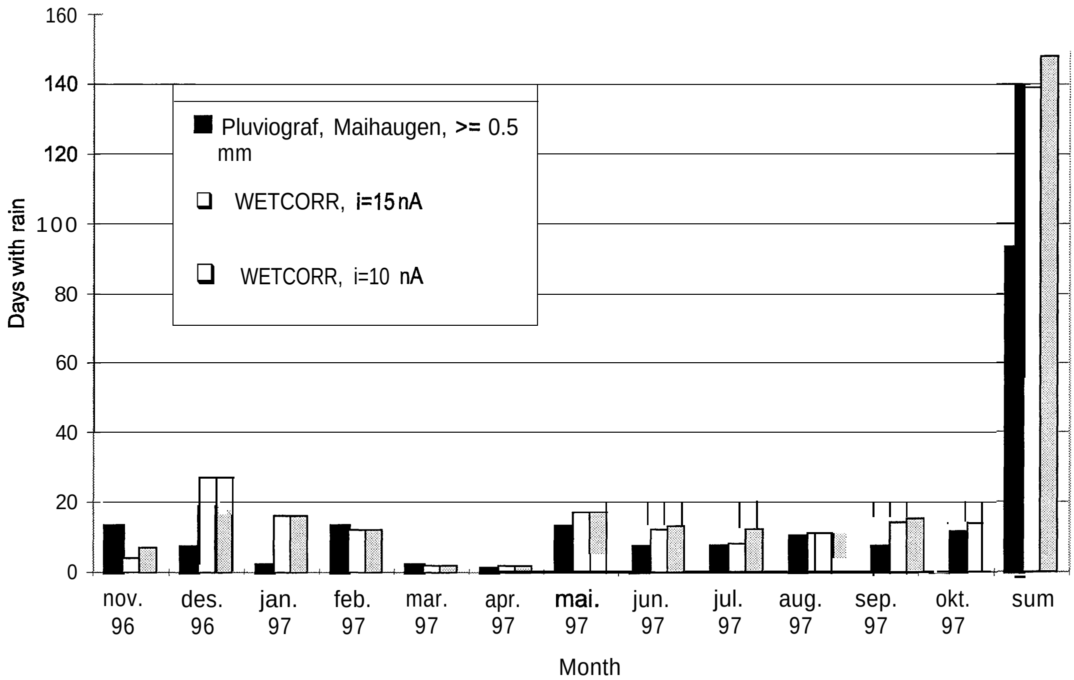

Fig. 3. Days with rain measured with pluviograph and WETCORR sensors at Hjeltarstua, Maihaugen.

3.2 From local to micro level

On Hjeltarstua the surface wetness was measured at 17 selected outdoor locations in the micro environment on the building and on 3 locations inside. The moisture content of the log construction was measured with INWOOD sensors at 20 locations. Table 1 gives an overview of the selected sites.

Table 1. Selected micro environment locations on Hjeltarstua and the type of sensors used.

	Sensor					
Adapter	a	b	c	d	Comments	Direction
SA01	IWT,BS	IW, P	IWT, BS in	IW, P	external gallery	North, N
SA02	WC, BS	IWT, BS	WC, P	IW, P		North, N
SA03	WC, in	IW, in	WC, out	IWT, out	external gallery	East, E
SA04	WC	IW	WC	IWT		South, S
SA05	WC	IW	WC	IWT	c, d; shelter	South, S
SA06	WC	IWT	WC	IWT	shelter	West, first floor, W
SA07	WC window frame	IWT window frame	WC	IWT	inside	South in, S
SA08	WC window frame	WC window frame	WC window frame	IW EGW		South, S
SA09	WC	IWT	WC	IWT		South, S
SA10	**WC**	**IW spruce**	**IW pine**	**T**	**rack**	**South, S**
SA11	WC EGW	IW EGW	WC window frame	WC window frame		West, W

WC = WC-sensors
IW = IW-sensors
T = temperature
IWT = IW-sensor with temperature

BS = bottom sill
P = post
EGW = end-grained wood

Cultural houses have their design based on traditions and experiences for protecting the building against rain and snow. The results obtained from measurement on a rack can hardly be expected to be representative for the wetness impact on the building parts. By using a current level of 15 nA as a limit for days with moisture on the wood surface, the WETCORR sensors will give both monthly average temperature and days with moisture. Scheffer's climatic risk index can then be calculated for all selected micro areas of the building. In Figure 4, CRIs for the period of November 1996 to October 1997 for all micro sites are shown.

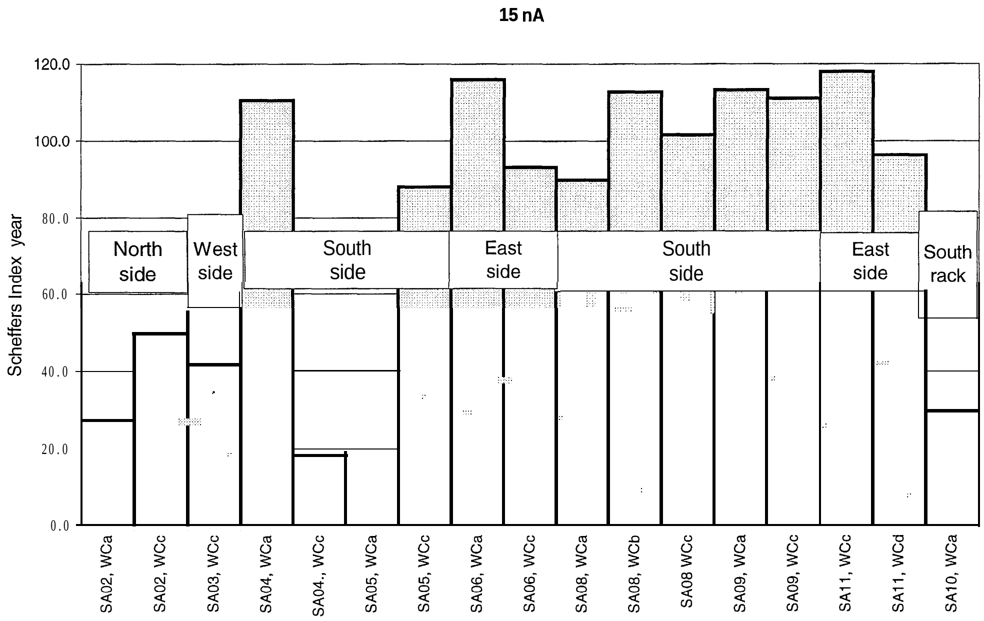

Fig. 4. Scheffer's Climatic Risk Index (CRI) for all micro sites measured on Hjeltarstua, Maihaugen

For most building locations CRIs are approximately 4 times higher on the wall than on the rack. However, a study of continuous measurements shows that there are only a few episodes and a few places where rain itself hits the wall. Mostly the wetness on these sites was formed by moisture adsorption in the deposited of hygroscopic dust particles on the walls and on the sensors. This effect is illustrated in Figure 5, where the number of days per month with current above 15 nA for four sensors on the wall and one on the rack are given. SA10 is the sensor on the rack where rain wash the sensor regularly and the number of days is the same as for the pluviograph. For the sensors SA04 on the south side and SA11 on the west side, dust deposition increases over the months and after six months almost all days have periods with current above 15 nA. On the north side (SA02) the effect is similar, but in July a rain event washed both sensors. The north facade has a wood gutter where the run off will be concentrated at leaks and at the ends. This creates water splash from the gravel ground. This part is also the only part where the INWOOD sensors indicated high moisture content in the structure.

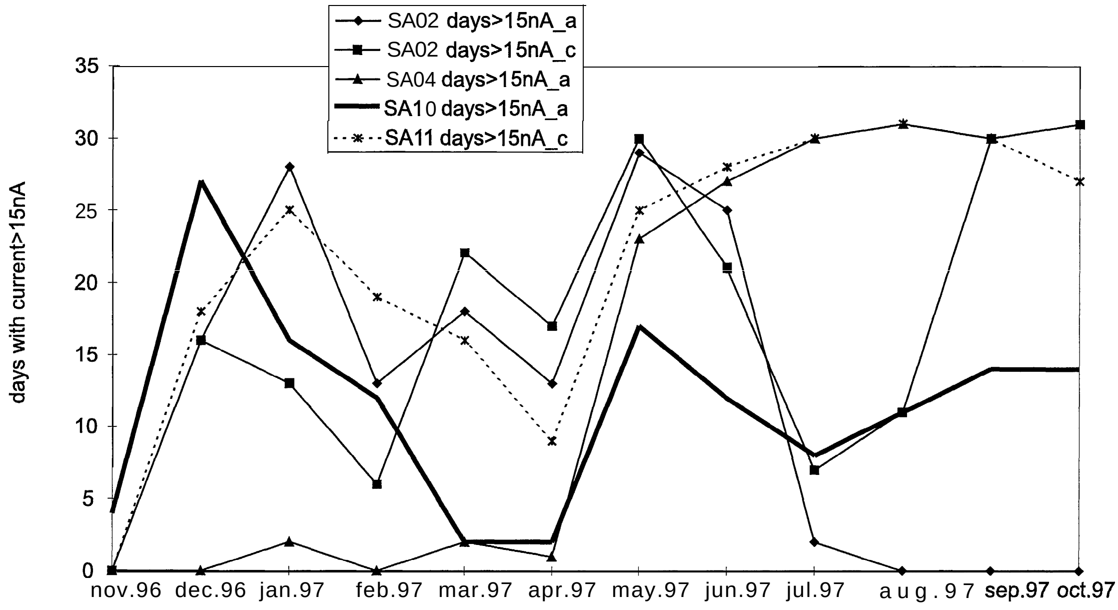

Fig. 5. Days with current respond above 15nA for sensors on the walls SA02, SA04, SA1 1 and on the rack SA10.

Inland, in the East part of Norway, driving rain is fairly rare. Walls seem to be wetted mostly by deposition of hygroscopic dust and rarely by a rain event. Since old log houses were built from resinous pine the water adsorption into the log is minor. The observed surface moisture will therefore react on the surface and quickly dry out in sunny weather causing only minor effects. Risk for rotting occurs mainly on parts with risk of standing water or capillary absorbed water present. This is observed on the north side connected to leakage from the gutter and to small parts of the stone foundation where water was running to the logs instead of away from them. On the micro level, either days with rain or the amount of rain seem to be as important as the duration of wet structures. The duration of wetness is more affected by the building techniques used and the craftsmanship. Old houses having low foundation are susceptible to water slash from the roof and gutters like that observed on the north side of Hjeltarstua.

The rain impact on freely exposed panels differs from the impact on a building facade. The effect of a rain event on freely exposed wood is shown in Figure 6. During the rainy episodes 1 and 2 of July the moisture content exceeded 25% for both spruce and pine panels and it took two days before the moisture content came under the 20% limit for fungi growth.

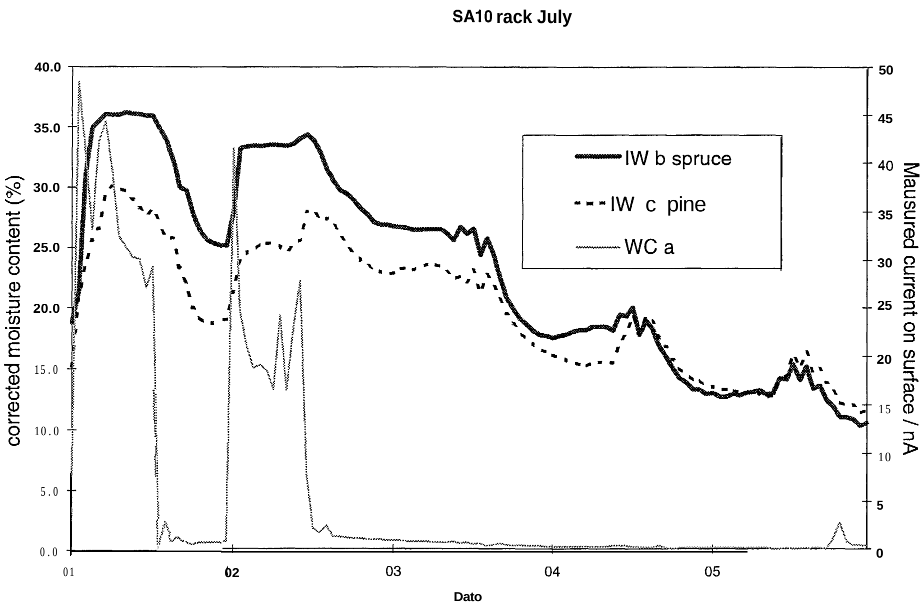

Fig. 6. The variation of the moisture content (%) in freely exposed panels during the period 3-6 July 1997 compared to the current on the WETCORR sensor.

4 Modelling climatic parameters

Scheffer's concept of using available meteorological data for estimating the risk for rotting is a good approach for predicting the rotting risk of wood. However, meteorological observations are collected at a limited number of places and different parameters are reported from different sites. To calculate the weather impact on wooden houses at a given location, several weather parameters are needed. To obtain these parameters it is necessary to generate values from the observation sites to all points in an area.

The GRID application in ArcInfo is a suitable tool for modelling of climatic parameters. GRID is a cell-based GIS system with several mathematical and geographical functions for calculating cell values.

4.1 Method

Based on the observations gathered within a given region, a statistical interpolation method (KRIGING) is used to distribute values to every cell. The dependence of local topographic effects on the meteorological observations is taken into account as well as the shadded and sunny sides of hills and mountains. Temperature cell values are recalculated from the differences between the height levels of the cells.

4.2 Input data

The objective in the development of the pilot version was presenting regional maps for temperature, amount of rain, and Scheffer's index for a part of the South-East region of Norway. Within this region the following data was collected:

- Temperature, amount of rain and days with rain as monthly and yearly data for 105 meteorological sites.
- Geographical points with height values for the 105 sites.
- Correction values for temperature height differences between the cells and for sunny and shady side of hills.
- Topographic maps of the region processed from contour lines to polygon data

4.3 Results

The result of the temperature plot for July values is given in Figure 7. The correction factor for height was 0.6°C for 100 meter and the same for sun and shade. Tests run for the other monthly and yearly data showed that the same factors could be used for all average values.

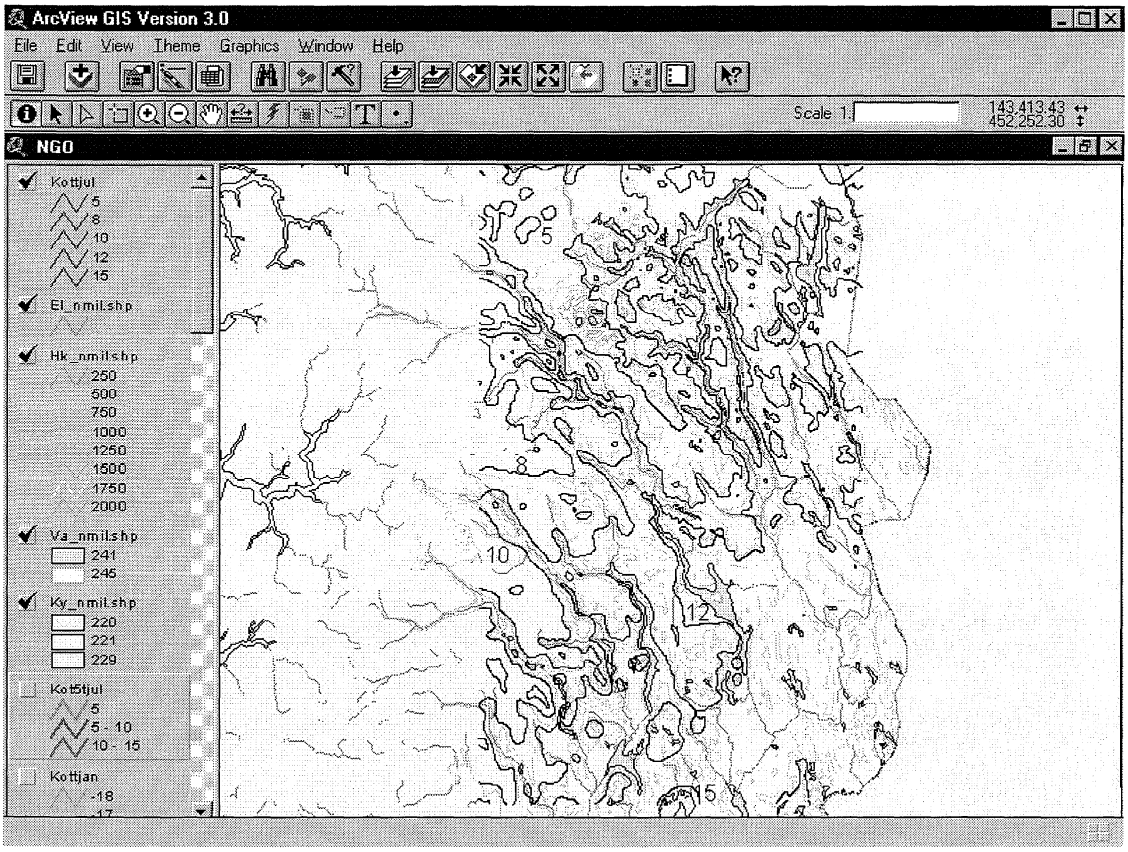

Fig. 7. Iso-line maps for the average July temperature distribution for a region of South-East Norway.

There are considerable differences in the amount of rain falling in different parts of Norway, it ranges from 3500 mm per year at places on the West coast to 300 mm in the upper valleys in East Norway. Within the modelling region the variation is 300 mm to 1200 mm per year. On a regional scale it turned out that we did not need to take into account the influence of hills and wind direction since we had sufficient meteorological rain observations in areas with rain shadows to form a reliable model for the amount of rain.

Scheffer's index uses the number of days with rain. The number of days with rain is not regularly reported for all meteorological sites in Norway. From the available number of days with rain data the model turned out to be less reliable than for the precipitation model. However by comparing the data sets where both rain amount and days with rain were available it turned up that number of days with rain was nearly independent of the amount with rain. An average value for days with rain can therefore be used for the whole region and the variation in Scheffer's index in the region will be entirely dependent of the variation in temperature.

For East Norway the input data for calculating the Scheffer's index will then be the monthly average values for temperature in each cell and a monthly average number of days with precipitation for each month used in all cells.

5 Conclusions

This study has shown that it is currently possible to model the temperature, precipitation and the Scheffer's index on a regional scale even in areas with large variations in topography as in Norway. The model could easily be adopted to other areas with smoother topography. In even rougher terrain such as in Western Norway greater concern must be given to local variations in precipitation parameters.

Providing information on days with precipitation and Scheffer's index does not seem to reflect the variation in rotting hazard in Eastern Norway. The duration and amount of wetting seems to play a more important roll. Even if a more precise equation could be formed, it would not solve the importance of the local influence to a building and the design of the building itself.

In the Lillehammer area the variation in Scheffer's index between two measuring sites 0.5km apart could be between 6 to 20%, and on the micro scale on a building even more. The WETCORR instrument is shown to give reliable data for time with rain with an open exposed sensor. The temperature sensor on the WETCORR sensor will also give information about the type of precipitation like rain or snow.

On the micro scale the WETCORR sensors are reacting to every type of moisture formed on the surface. The various events like rain dew or snow have different current characteristics and can be separated by interpretation of the continuous current record. Hygroscopic particles will form a moisture film on building substrate. On more susceptible materials than resinous pine this will increase the hazard for rotting or surface discoloration from mildew. On other materials, such as metals it would also increase the corrosion hazard.

6 References

1. Scheffer, T.C. (197 1) A climatic index for estimating potential for decay in wood structures above ground, *Forest Products Journal,* Vol. 21, pp. 10-25.
2. Henriksen, J.F. and Haagenrud, S.E. (1994) *The EUREKA project EU 615 EUROCARE WETCORR.* Report from the NBS-MK Seminar at ABB Conference Centre, Billingstad, 24 November 1993. Lillestrøm, Norwegian Institute for Air Research (NILU OR 37/94).

Investigations of Mass and Energy Flow in the Existing Building Stock

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Summary

The complexity and dimensions of interlacing of buildings with environmental effect – shortage of raw materials, waste removal problems, global warming effect etc. – requires a reduction of mass and energy flow in civil engineering in the future. One of the most important necessities for this is to preserve the existing building stock. Within the framework of investigations regarding "building material usage and the primary energy input for residential buildings constructed at different times", 20 residential buildings of varying ages (typical examples of solid-wall type of construction) were examined with regard to their building material and mass composition. In addition, the primary energy contents of the buildings concretized in the form of building materials - the so-called accumulated energy expended in the production of the building materials (PEI,) - was also determined. The purpose of the investigation is to obtain information regarding the composition of building materials in residential buildings dependent on their age, and thus gain knowledge for dealing with existing buildings. As results we have found characteristic values for the material composition and the primary energy inputs of buildings from different age groups.

A crucial finding, apart from the relationships and dependencies of building material masses and primary energy input, is the dependency of used building materials and construction methods in the case of residential buildings of earlier building age groups on their age group. It becomes apparent that a change of the used building materials as a rule concurs with a change of the constructive composition. As a conclusion from this finding one derives a *"Building Element Catalogue to Register and Assess Existing Residential Buildings".* The compiled constructions extend over a time span from 1890 to 1970 and concentrate mainly on building construction in urban multi-storey residential buildings.

To shown the influence of the period of use we have investigated three single family houses: A house built in accordance with the German thermal protection ordinance (WSVO), a low-energy house (NE-H) and a so-called passive-solar house (P-H). As results of analyses the mass flow and the cumulative total energy necessary for the production, maintenance and operating of the three buildings over a period of 80 years are presented.
Keywords: mass and energy flow, material composition, primary energy input

1 Composition of Building Materials of Buildings Constructed at Different Times

Fig. 1 shows the total masses of the used building materials of all examined residential buildings related to their gross cubic content, represented as columns. A mean value of 0.528 Mg/m³ gross cubic content is obtained for all examined buildings. It is apparent that single family houses (mean value 0.592 Mg/m³ gross cubic content) tend to be heavier due to their higher proportion of building materials; the used building materials here normally enclose a smaller volume than for residential buildings for several families (with a mean value of 0.479 Mg/m³ gross cubic content).

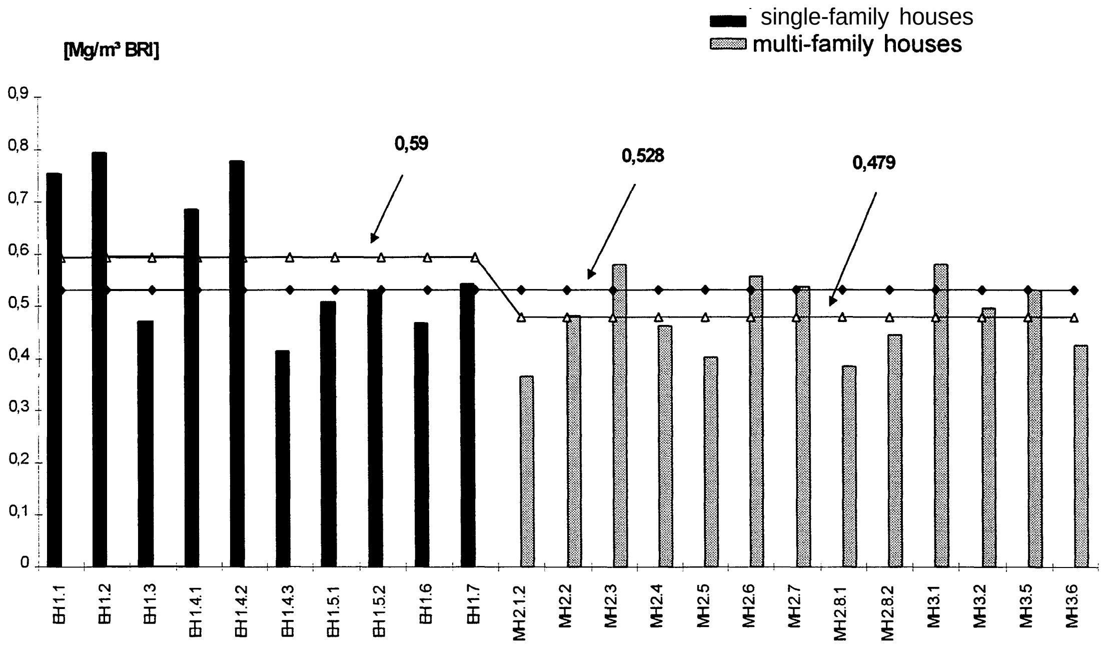

Fig. 1 Building Material Masses of the Investigated Buildings in Mg/m³ Gross Cubic Content [1]

The breakdown of the building material masses into the individual building material groups in fig. 2 shows the dominance of the mineral portion in examined buildings.

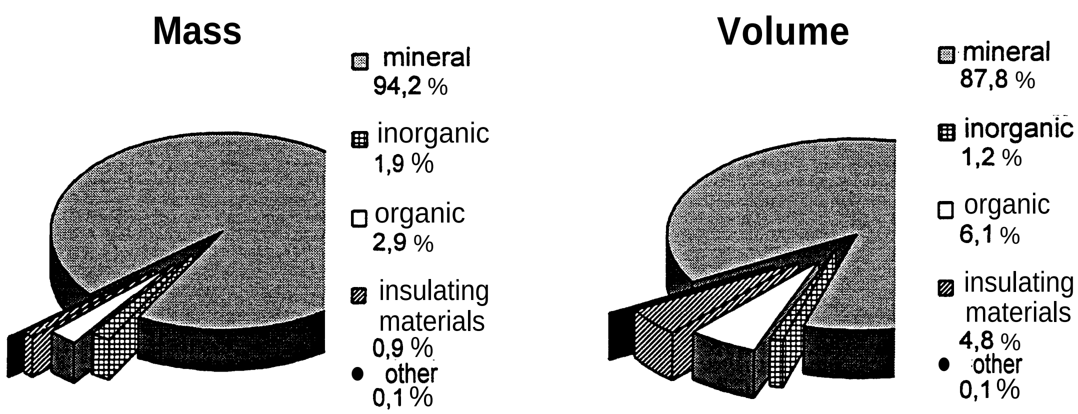

Fig. 2 Classification of the Building Material Masses in the Building Age Groups Averaged into Mass and Volume Percentages [1]

It can be recognised that the portion of the organic materials and the insulating materi-als have a greater weighting in the percentage by volume. This can be put down to the fact that these materials, in comparison to the mineral portion, have a lower specific weight at the same volume.

Figure 3 shows the usage of building materials in residential buildings as changing with time as a mass percentage distribution. It can be seen that the composition of the building materials changes from one age group to the next. Whereas the concrete portion has increased since the mid 1920's, the portion of timber as an organic building material has decreased to under 5 %. Although the buildings of the age groups from 19 18 to the present day are mainly examples of the solid-wall type of construction, the portion of block and brickwork walling decreases in this presentation. This illustrates the fact that the increased use of concrete is not only at the expense of the building material timber but also block and brickwork walling. The building materials clay and slag, which were still often used at the beginning of this century in timber beam ceiling constructions, have almost completely disappeared since World War II. In comparison, a continual increase in the use of inorganic materials such as glass and steel as well as insulation materials can be observed. The proportion of the collective group mortar/plaster/gypsum remains generally stable.

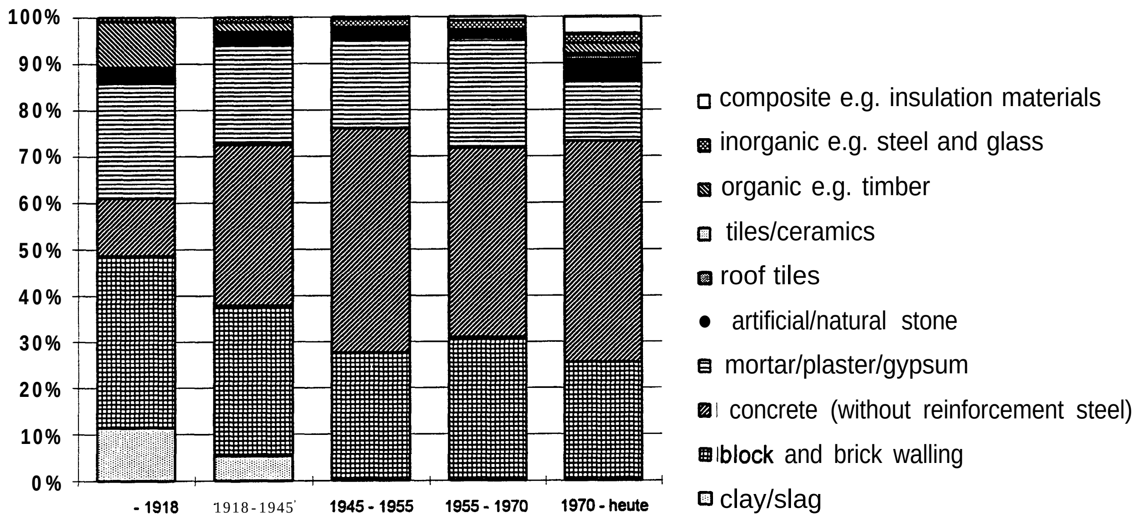

Fig. 3 Usage of Building Materials in Buildings of Various Age Groups as a Mass Percentage Distribution [1]

Fig. 4 represents the distribution of building material masses in loadbearing structure and finishes. The illustration shows that more than 80 % of the building material masses of the examined residential buildings can be apportioned to the loadbearing structure, and less than 20 % on the finishes. A displacement of the building material masses from the loadbearing construction to finishes is recognisable in the younger building groups. This emphasises the increased use of building materials in the area of finishes due to the increasing requirements made for thermal and sound insulation. It is also of interest to note that for buildings constructed prior to 1918 the internal finishes also have a greater weighting. This tendency is accounted for by the fact that one then constructed the intermediate floors using timber beams, and the spaces between these beams were filled with sand, clay and slag. The use of timber and clay/slag in the building group prior to 19 18 is also documented in figure 3.

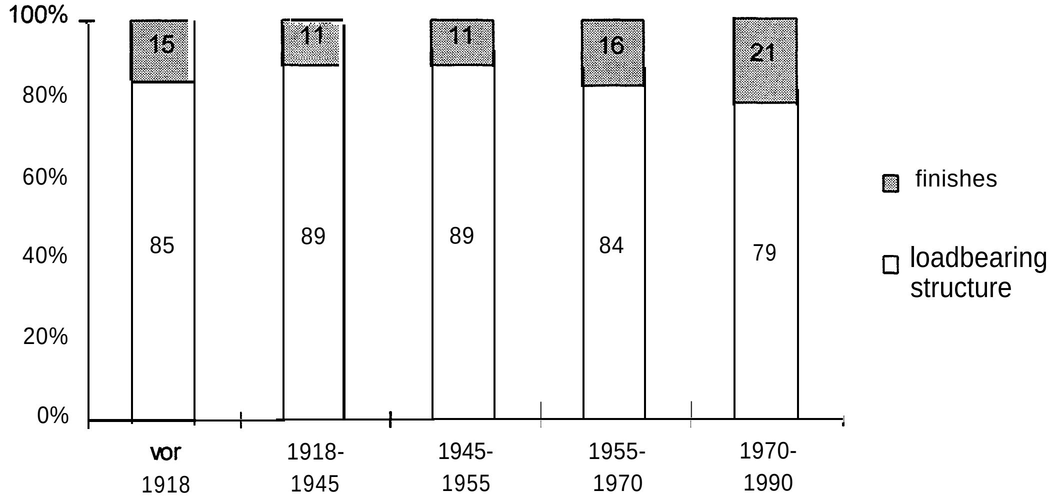

Fig. 4 Distribution of Building Material Masses in Loadbearing Structure and Finishes [1]

The average proportion of the individual building element groups in the total mass of all examined residential buildings, given in fig. 5, shows the dominance of external walls and floor/ceiling construction each with a value of 3 1 % for multi-family houses, followed by internal walls with 21 %. For single family houses the proportion for external walls with 39 % is much more characteristic, instead the floor/ceiling construction portion is barely 21 % and the internal walls with 14 % are of less influence. Taking the external and internal walls together, it becomes apparent that the proportion of the walls for single and multi-family housing in total are almost identical with just over 50 % of the total mass.

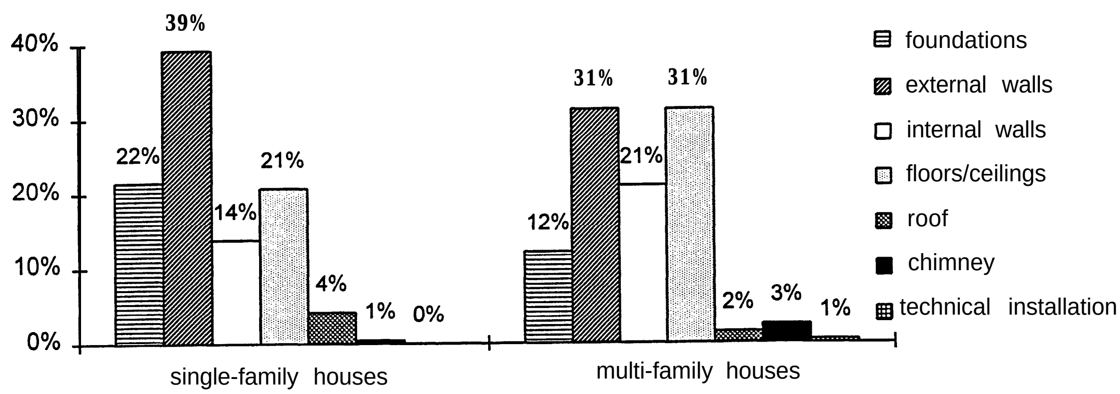

Fig. 5 The Average Proportion of the Building Element Groups in the Total Mass of the Examined Single Family and Multi-Family Houses [1]

Furthermore it can be seen that the building element groups foundations and roof are of greater weighting for single family houses. This shows that the discernible tendency of the higher average building material masses of single family houses, given in figure 4, is mainly to be found in the values for foundations and roof. This seems logical, as just in the foundations the elements foundations, floor slab and cellar walls are often dimensioned and built for constructional or static reasons, for example to act against lateral soil pressure. A dependency on an increasing number of storeys only becomes apparent after 5 - 6 storeys. The building material mass of the roof is however independent of the building height; it is determined by the built-over area and the roof shape. With increasing building height, the influence of the roof is thus clearly less.

2 Production Energy Input for Buildings

The examination of residential buildings with regard to the cumulative production energy input (PEI_H) carried out on 20 buildings has shown that the basic primary energy input values for the building materials are not decisive but rather the building material mass, defined by the specific material density. Figure 6 shows the total sums of the building material masses and the cumulative production energy input (PEI_H) related to the gross cubic content for give chosen residential buildings in a co-ordinate system. The buildings are 4 - 5 storey multi-family residential buildings, in each case a typical representative of solid-wall type construction for the given building age group. It can be seen that all five buildings vary around the value PEI_H/mass = 2 GJ/Mg. It can also be seen that the building in the age group 1945 - 1955 is not only the heaviest but also has the highest PEI_H value; nevertheless however its relationship PEI_H/mass is more favourable than for buildings of the following building age groups.

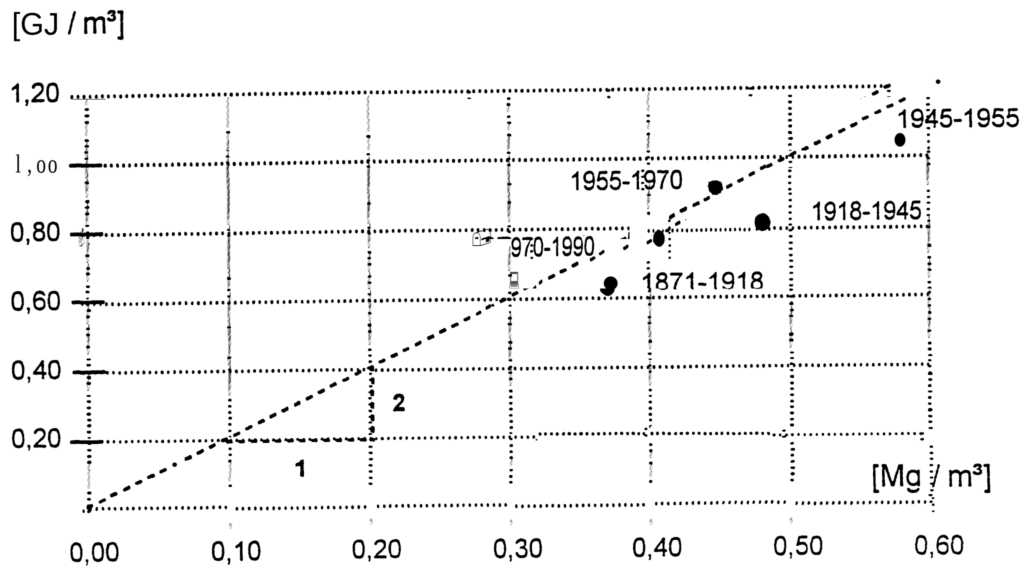

Fig. 6 Related Total Values of Building Material Mass and Primary Energy Input for the Five Multi-Family Houses [I]

Figure 7 shows the related building material masses and PEI_H for three multi-family houses, classified into building element groups in accordance with DIN 276.

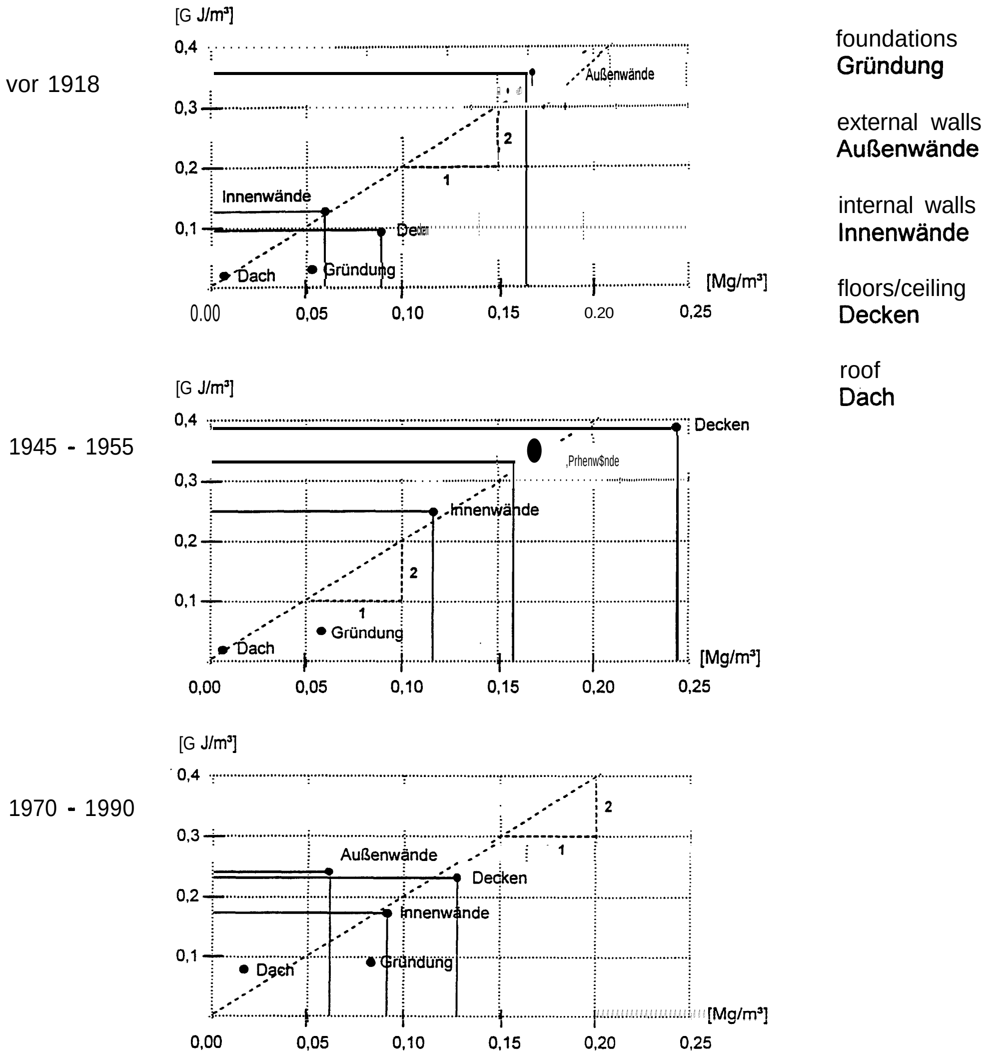

Fig. 7 Related Building Material Masses and Primary Energy Input for Three Multi-Family Houses [1]

Common for the examined buildings is the fact that the external walls and floor/ceiling construction are the dominant building element groups. For the building in the age group prior to 1918 it can be clearly observed that the external walls determine the size and level of the PEI_H value. If one examines the multi-family house constructed in the age group 1945 - 1955, a visible increase of the building element groups internal walls and floor/ceiling construction is noticeable compared to the building of the older age group. Not only have the absolute values increased mainly for the floor/ceiling constructions but also the level of PEI_H/mass has slightly increased. For the third building represented in figure 5.19 - in the youngest building age group from 1970 - 1990 - it is seen that the absolute values for the building element groups external walls and floor/ceiling construction have decreased again, and the individual building element groups are in closer proximity. It is noticeable that the PEI_H/mass level of the external walls has visibly increased. The building element group for foundations shows the lowest PEI_H with a value of approx. 1 GJ/Mg for all buildings.

3 Material and Energy Flow in Buildings During Their Use

In the following, the results of analyses of the material and energy flow in three single-family houses over a period of 80 years are presented [7]. A house built in accordance with the German thermal protection ordinance (WSVO), a low-energy house (NE-H) and a so-called passive-solar house (P-H) have been used as examples. Fig. 8 shows the cumulative building material masses of the three single-family houses in comparison. The stepped course of the curves result from the fact that individual building elements have to be replaced when their useful life has ended.

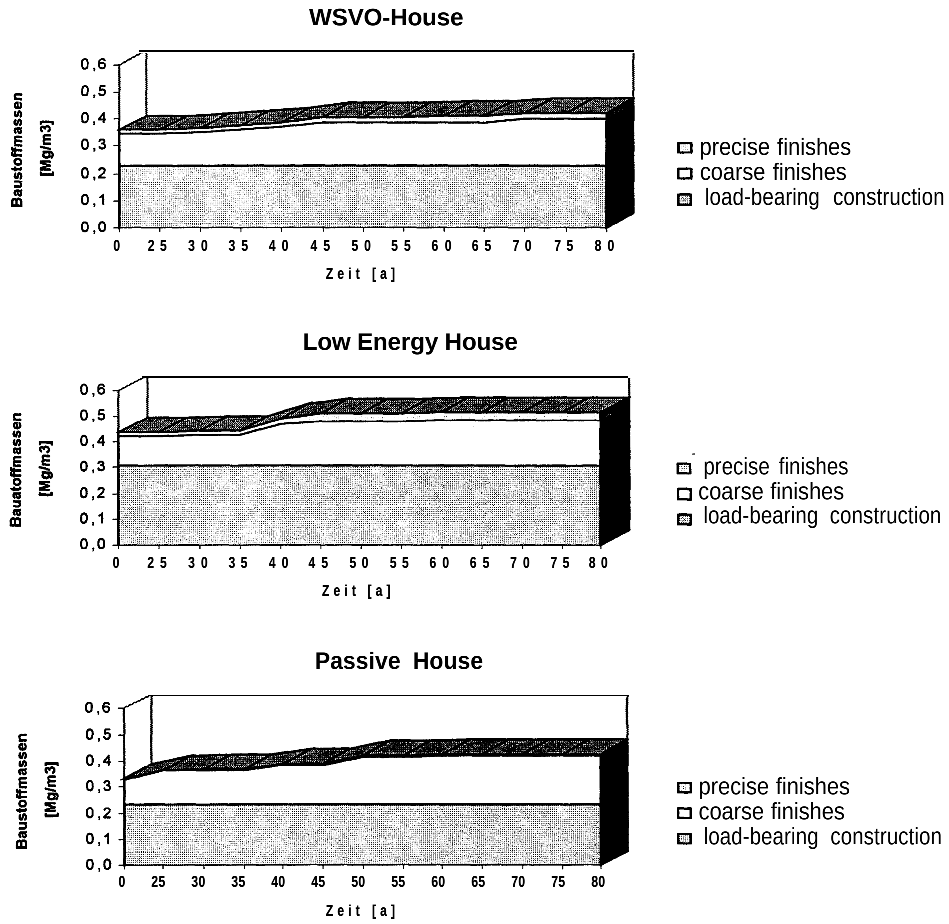

Fig. 8 Cumulative Building Material Masses of Three Single-Family Houses Over a Period of Use of 80 Years [2].

It can be seen that the finishes gain in importance within increasing length of use. In the case of the passive house, for example, the building material masses of the coarse and precise finishes have almost doubled after a period of use of 80 years due to maintenance measures. Fig. 9 shows the cumulative total energy necessary for the production, maintenance and operating of the three buildings. It becomes clear that the production, maintenance and operating of the three buildings. It becomes clear that the primary energy consumption for heating and the production of hot water is a multiple of the energy input for the production and maintenance of building materials in the case of a house built in accordance with the German. thermal protection ordinance. Even though the primary energy expended in production (PEI_H) for the passive house is almost double that of the building in accordance with this thermal protection ordinance, in the period of use the saving of energy clearly outweighs in the total audit.

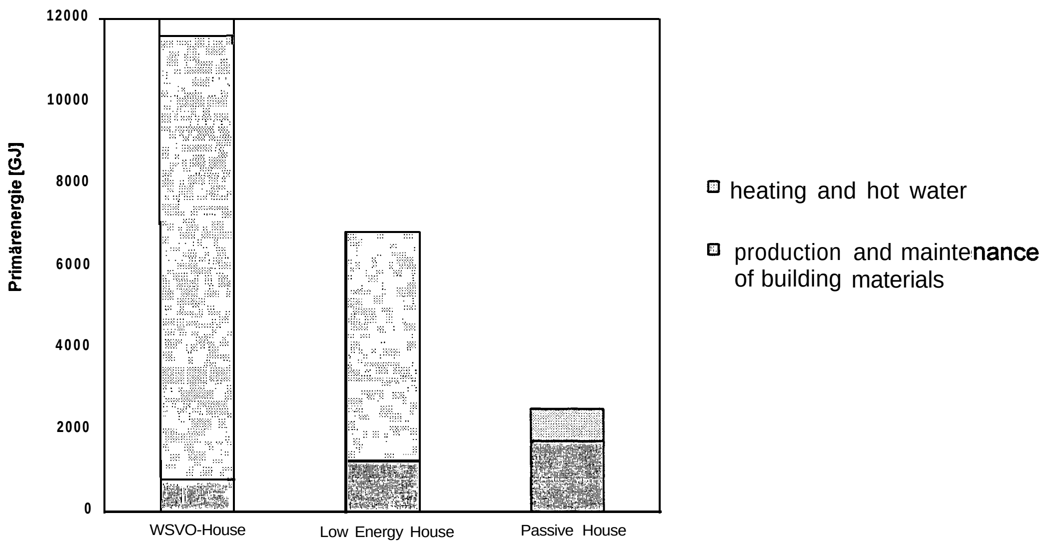

Fig. 9 Cumulative Total Energy Expenditure for Three Single-Family Houses Over a Period of Use of 80 Years [2]

4 Conclusions

In the future, the conservation and energetic restoration of the building stock will play an important role with regard to the reduction of material and energy flows in the building and construction industry. As shown in figure 4, more than 80 % of the building material masses in existing residential buildings can be apportioned to the loadbearing structure elements, and less than 20 % to the finishes. As normally the loadbearing construction of a building can be retained when larger alteration works are carried out, the preservation of existing buildings as well as the reactivation of empty buildings firstly contributes to the avoidance of residual building mass and disposal site volume, and secondly saves building material and energy resources.

5 References

1. Wörner, J.-D., Kloft, H. (1997) *Untersuchungen zum Baustoffeinsatz und zu den Primärenergieinhalten von Wohngebäuden verschiedenen Baualters,* Forschungsbericht, Institut für Statik, TU Darmstadt.
2. Kloft, *H. Untersuchungen zu den Material- und E nergiestrdmen im Wohnungsbau,* Dissertation in preparation.

The programming of plaster surface maintenance by the 'evolution scheme' approach

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Abstract
The historical building renewal requires procedures and methods to control degradation and obsolescence, in order to program the material and building system maintenance and to guarantee high quality interventions. For a fast reliable of constructed facilities, the individuation of variables affecting the building degradation and the study of their behaviour with time is the fundamental step [1]. The paper describes the use of diagnostic activities, based on the in situ alteration analysis, in the case of plaster surface renewal. The management information system connects data coming from different analytic methods in order to draw the life-cycle of the outside building finishing. To allow programmed maintenance operations, the identification of the contained alterations must be associated with the hypothesis of their development during the time. The simulation of degradation-induced phenomenon reduces doubts in the selection of intervention choices, allowing to program the maintenance. In addition, economical benefits and advantages for the maintenance management are possible too. The approach aim is to encourage the prompt intervention operations, restoring the initial bulding performance.
Keywords: plaster alterations, historical building life-cycle, maintenance program.

1 Introduction

So far the plaster degradation has not been considered as a progressive process and the produced damages never have been seen as product of a damage evolution. However, the consequences of the prolonged presence of degradation causes and the interaction with additional causes, able to increase significantly the damages, must be taken in account. The damage observed on the plaster surface is produced by the continuous action of agents coming from the environment (external agents) and the substrate (internal agents). In fact, the plaster is constituted of a number of superimposed mortar layers, that bond the wall surface regularising its discontinuities, so to give a homogeneous external flat surface with the function to protect the wall from environment factors [2,3]. Therefore, this component is equivalent to a filter, that interposed between wall and environment modifies the exchanges and suffers the degradation events. The included alterations are the effect of disturber phenomena that find their origin and their evolution in the environment, in the wall, and in the plaster layers.

In the building renewal, the acquisition step is of fundamental importance to select the operations required to achieve high quality results. Frequently, poor results are obtained because the analysis has been performed by inadequate methods. However, in addition to suitable analytical methods of investigation (destructive and non destructive tests), a complete set of rules and techniques always is required to assure efficacy and efficiency to the acquisition step. In fact, only the organisation of the complex sequences of analysis results and general information (i.e., building age, technologies used, environmental context, etc.) can allow the formulation of a right diagnostic hypothesis.

In the present paper, analysing the problem of the plaster surface renewal, it has been shown as diagnostic operations [4] can be developed on the basis of in situ observations of latent and visible surface damages.

2 Methodology section

The development of a specific lexis for the different alterations (visible and latent damages) that can be present on the plaster surface is required to give a rigorous organisation to the damage identification. Such identification is important to develop a correlation between plaster morphologic characteristics and specific alterations involved. The use of a lexis allows to perform two important objectives: first, it gives a common terminology to operators of this field of activity, and, second, it directs the operator among the several alteration causes. The proposed lexis is a re-elaboration of a standard terminology [5]. The three fundamental alterations classes and the specific alterations associated to each class are the following:

Deformation: change of the original geometric characteristics of the plaster surface and continuity parameters.

1. Alveolization;
2. desegregation;
3. separation;
4. erosion;
5. breaking;
6. lack;
7. swelling;
8. pulverisation.

Foreign material comparison: presence of foreign materials, stacked to the below surface, modifying the plaster surface uniformity.

9. Efflorescence;
10. coherent and incoherent surface deposits.

Chromatic heterogeneity: alterations of the chromatic uniformity of plaster surface.

11. Change of the original colour;
12. biological coat;
13. spot.

The degradation process can progressively increase with time. Such an increase can be due to the continuous presence of degradation causes, but also to the presence of additional causes, produced during the damage development [6]. In particular, the initial situation, characterised by a decrease of the performance levels relative exclusively to some specific properties, can be followed by a reduction in the performance levels relative to a different set of properties, with consequent changes in the initial conditions [7]. The prevision of the degradation phenomenon progress during the plaster life-cycle allows to perform a programmed maintenance of the surfaces so to reproduce their initial characteristics [8]. Only a suitable analysis and identification of the damages appeared with increasing of the degradation can assure efficacy and efficiency to the renewal. For this reason, all possible alterations must be organised in an evolution scheme where they are located in a logic sequence. Figure 1 shows the latent alterations that can be revealed during a periodic control by not destructive methods (e.g., thermography). Such alterations assume a recognisable 'appearance only with the increasing of degradation.

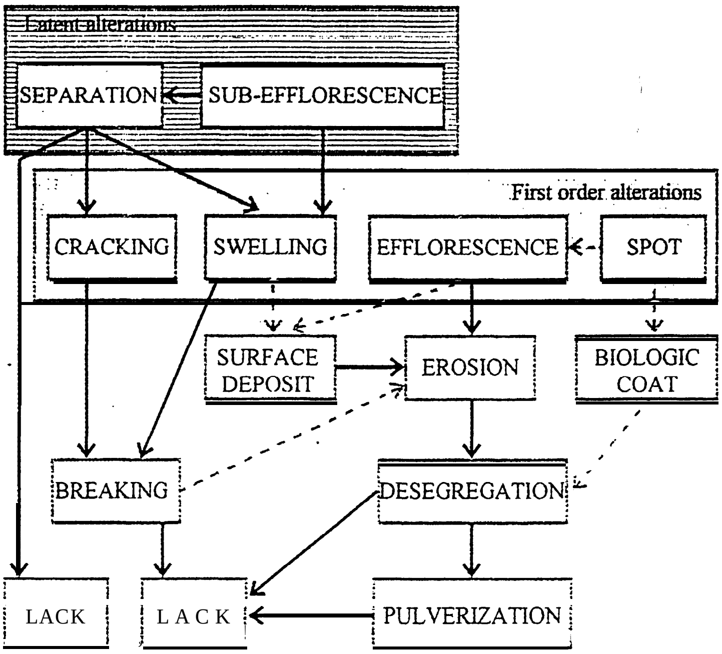

Figure 1 - The evolution scheme of alterations.

If the first order visible signs (read at initial time) are not totally solved by the renewal operations, they inevitably further develop. Consequently, higher order alterations, that cause processes able to transmit the degradation to the support wall, can result. In fact, the degradation progress leads to particular alterations, which are characterised by a more serious plaster and wall damage. The behaviour of the damage growth is influenced by several factors: plaster age, environment (i.e., building orientation and height, climatic conditions, air pollution, etc.), nature of the support and plaster materials, fabrication technology used, etc.. On the basis of all these factors, the degradation direction for both the support and plaster components can be statistically predicted for the particular environment present. However, when the plaster surface of the façade is damaged in several points, it becomes possible to formulate the hypothesis on the dynamic process characterising the degradation. Such hypothesis allows to perform renewal operations before that damages become excessively serious in some points of the façade.

In Figure 1, the continuous lines represent the visible signs included in the degradation ways started from one of the possible alterations. In addition, it has been observed that the production of some -particular alterations produces the favourable conditions for the development of new alterations. In this-case, such new alterations are produced only because ofmorphologic and physic-chemical surface modifications of the initial damage state. For example, the plaster surface swelling, can promote the surface deposit production and/or thekfflorescence. Also the efflorescence, producing micro-discontinuities on the plaster surface, easily accepts surface deposits.

Among the diagnostic systems for the study of latent damages [9,10], the thermographic analysis [11] is a very important technique that allows to obtain information on the full' plaster surface. The thermographic analysis is performed by a camera-video having a semiconductor sensor sensible to the infrared radiation. The study of the alteration processes requires the determination of microstructural and physic-chemical characteristics of altered and intact materials, and their comparison. Also in the case of plaster separations, the latent alterations can be revealed by a thermographic investigation. In particular, the presence of regions characterised by higher isothermal levels is indicative of plaster separation phenomena. The higher emissivity of regions where a separation is present is due to the higher wall ability to follow the environment temperature variations. The capillary phenomena, which progress produces damp spot and separation, are characterised by isothermal levels lower than the façade. The thermography, showing the real boundaries of a only partially visible phenomena, allows to obtain a damp distribution map before to have soluble salt diffusion processes, spot formation, and plaster separation. The analytical method can involve the microscopical investigation of samples (altered/intact materials) to reveal the morphology, colour, and consistency differences. The altered plaster/substrate interface has to be analysed to individuate the presence of compounds as sulphates, chlorides, nitrates, etc. (i.e., sub-efflorescence). The analytical investigations are performed by chemical methods, x-ray diffractometry, and IR spectroscopy. To value the phenomenon diffusion and to know the functionality loss of the plaster is required to perform the same analytical investigations on the full plaster section. Also a physical characterization of the plaster can give useful information.

The breaking is revealed by the presence of a large number of widespread micro-cracks or a low number of large cracks. Usually, the breaking can develop lack, because it can be originated at substrate-plaster interface. The breaking starts in the interior material or between the plaster layers (because of fabrication defects) and propagates up to surface, producing a partial plaster separation. When the process involves several plaster layers, the size distribution analysis of the inert contained in the different plaster layers allows to establish the presence of fabrication defects. When the plaster easily detaches from the substrate, the plaster-substrate interface has to be analysed to value the presence of new compounds that, producing a pressure on the plaster, cause the cracking.

3 Discussion

The Maria SS. Dell'Addolorata church, inserted in the S. Sofia conventual complex, was fabricated in the IX Century and it has undergone several changes and additions principally during the XIX Century. The main façade (see Figure 2) contains a stone-made base surmounted by pilasters with Corinthian capitals and by a bas-relief medallion in the middle. Geometrical figures representing bricks are present on the plaster surface contained between the pilasters. The individuation of the alteration evolutive process is possible on the basis of an analysis of alterations contained in the façade, shown in Figure 3.

Different damage levels can be observed in the building façade (Figure 3). The separation is the most frequent damage, and, therefore, the following evolution ways are possible:

- separation-lack;
- separation-cracking-breaking-lack;
- separation-swelling-breaking-lack.

The presence of a scarcely visible erosion alteration suggests the following additional evolution way:

- erosion-desegregation-pulverisation.

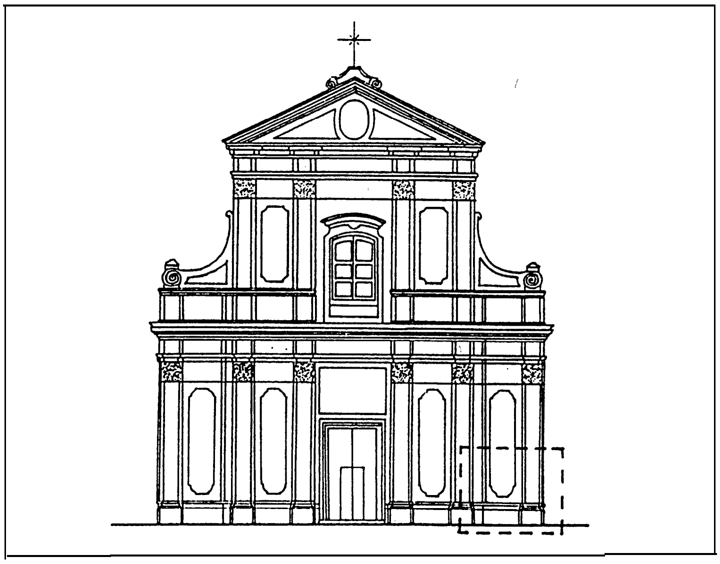

Figure 2 - Maria SS. Dell'Addolorata church Est-façade with the indication of the region containing the damages in Figures 4÷6.

Figure 3 - Maria SS. Dell'Addolorata church main façade.

The erosion can start from the presence of efflorescence or from the formation of coherent surface deposits, frequently, revealed during the investigation. The separation is the most evident damage and it frequently is present in the base region, where the contact is between materials characterised by different physical properties. In fact, as visible in Figure 4, the top of the base is not sensible to alteration phenomena, instead, the above plaster is almost totally lost.

Figure 4 **-** Alteration phenomena present at interface between base top and plastered wall.

It must be observed that, usually, the presence of a contact region between materials with significative porosity differences inevitably produces a large alteration of the higher porosity region. Such a behaviour is in accordance with the damages shown in Figure 4.

4 Conclusions

Starting from the analysis of the plaster surface alterations, it is possible to develop a diagnostic project including the investigations required for a complete phenomenon knowledge. Analytical investigations carefully performed allow the individuation of the causes required to the renewal operations. In addition, the individuation of the degradation evolution ways is required for an adequate maintenance programming [12,131. In the presents case, such approach allows the operations required to avoid the full plaster surface loss, so to reduce as much as possible the substrate damages. In the case of historical buildings, the possibility to foresee the plaster life-cycle reduces the material loss avoiding both modifications in the original nature (materials and shape) and application of the new plaster. In particular, the use of new plasters always has compatibility problems with the existing plaster and substrate performances [14].

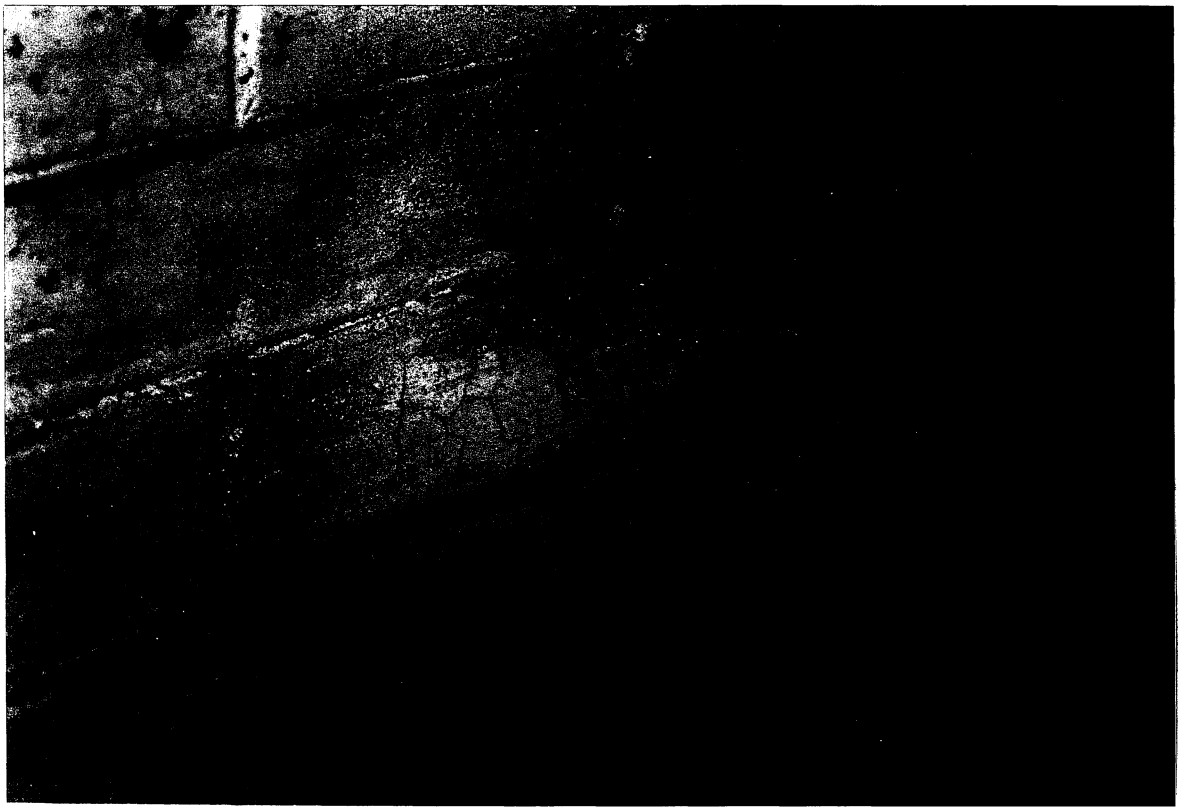

Figure 5 **-** Particular of the creaking alteration present in the façade.

Figure 6 - Particular of the lack and pulverisation alterations present in the facade.

References

1. Di Battista,V. (1989) *Il degrado delle materie*, in: Caterina, G. Tecnologia del recupero, UTET, Torino, pp. 27 l-273.
2. Biscontin, *G.* (1985) *L'intonaco: storia, cultura e tecnologia,* in: proceedings of Convegno di Studi di Bressanone, Libreria Progetto Editore, Padova.
3. Biscotin, *G.* (1990) *Super-ci dell'architettura: le finiture,* in: proceedings of Convegno di Studi di Bressanone, Libreria Progetto Editore, Padova.
4. Mader, G.T. (1988) *L'indagine conoscitiva,* Bollettino d'arte No.48 marzo-aprile, pp.1051 12.
5. *VORMAL recommendations:* 1/1988 "Alterazioni macroscopiche dei materiali lapidei: lessico".
6. Croce, *S.* (1994) *Patologia edilizia: prevenzione e recupero,* in: Manuale di Progettazione Edilizia, Vol. 3, Progetto tecnico e qualità, Hoepli, Milan.
7. Baronio, G., Binda, L., Contro, R. And Scirocco, F. (1979) La conservazione dei monumenti: metodologie di ricerca e tecniche di consolidamento contro il degrado, Proceedings of ASSIRCO Congress, Perugia, 6-7-8 November.
8. *NORMAL recommendations:* 20/1 985 "Interventi conservativi: progettazione, esecuzione e valutazione preventiva".
9. Brunetti, *G.* (1986) *Tecniche non distruttive per la diagnosi*, in: Bellini, A. Tecniche della conservazione, F. Angeli, Milano.
10. Castiglioni, A. (1989) *Le indagini diagnostiche per Z'intervento sui prospetti: Villa Fabio Ponti a Biumo Superiore,* Recuperare No.43, settembre-ottobre, pp. 546-55 1.
11. Romeo, *C.* (1996) *La termografia ed il suo impiego nell'analisi del manufatto architettonico,* Geda, Torino.
12. Proceedings of the International Congress: Conservation of Architectural Surfaces: Stones and Wall Covering, Venezia, 12-13-14 march, 1992.
13. Micocci, F., Pulcini, G. (1991)GZi *intonaci: Materiali, tipologia, tecniche di posatura e finitura, degrado e recupero,* NIS, Roma.
14. Masazza, F. (1984) *Interazione fra materiali antichi ed i moderni materiali di restauro: il comportamento chimico-fisico,* in: Carbonara, G. Restauro e cemento in architettura, Vol. 2, AITEC, Roma, pp. 162- 173.

Environmental assessment method adapted to buildings

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Abstract
This paper suggests an impact evaluation system for buildings called the Safeguard Assessment Method adapted to Buildings, SAM(B) The evaluation system corresponds to the step in a Life Cycle Assessment (LCA) called Impact Assessment. This means that the structure follows a LCA, suggested by ISO.

The assessment of buildings are divided in three themes; energy use (during service life), material flow and site specific values. Both energy use and material flow describes effects caused by the building and its utilisation. For a building the reverse is also relevant - the effect from emissions realised by anthropogene or natural sources. The reverse is taken into account in the theme "site specific values". For the moment only evaluation factors related to indoor air quality (IAQ) are introduced.

The evaluation system is based on the outcome of the inventory analysis from an LCA, except in the case of the site specific values which are based on in situ measurings. The suggested evaluation method in this paper is based on three safeguards. The safeguards are areas of protection, and here regarded as end points, which means that no further agglomeration should be performed. The safeguards are

- human health
- ecological systems
- resource efficiency.

Since the SAM(B) is still under development the only safeguard described in quantitative terms in this paper is related to the safeguard called human health. The evaluation is based on the concept "distance to target", where the target is equal to a "long time low risk concentration" of hazardous substances or comfort factors. Then a correction term is used to give an adequate evaluation of health aspects with serious risks compared to suffering and well-being in general. Preliminary figures for **17** emissions to air is given in Table 1.
Keywords: buildings, impact assessment, indoor air quality, life cycle assessment, safeguards, evaluation.

1. Introduction

Life cycle assessment (LCA) is a common tool for evaluation of the environmental impact from products and services. The result of an LCA study can for instance depend on:

- the aim of the study
- data quality
- system boundaries
- choice of impact valuation method.

The three topics given above are discussed in Erlandsson [1] for products assessment in general. In that report a development of LCA is described and called Life-Time Assessment (LTA). The LTA-method gives a solution to the problem with open loop recycling, one of the most critical points in the life cycle inventory part of an LCA. The LTA-method has then been further developed. How the LTA-method should be applied on assessment of buildings has been suggested in Erlandsson [2]. In this paper only the last topic given above - the choice of impact evaluation method - is discussed. A concept for an evaluation method (for buildings) is introduced.

2. The Safeguard Assessment Method, SAM

A general problem in developing of LCA to a user-friendly tool, is that it will be dependent on a reliable impact Assessment method. An evaluation method adapted to buildings must be extended (compared to an ordinary product-LCA for consumers products) to include adequate environmental themes valid for a building. Such topics are for instance contaminated soil, indoor air quality, possibilities for conversion, local environment and maintenance, choice of energy system, flexibility and water consuming. This paper presents a first conceptual approach for environmental evaluation of three areas of protection. These areas are called safeguards and the method is called **- the Safeguard Assessment Method, SAM.** Such safeguards as given in “Code of Practice“ by SETAC [3], are human health, ecological health and resources. In this paper however, these safeguards have been modified. The major remark is that the term health often includes more than only pure health aspects, such as general well-being. The safeguards discussed here are:

- human health
- ecological systems
- resource efficiency

An other difference between the original SETAC version and the safeguards in the SAM is that resource depletion is regarded as a monetary value and not treated at all as an environmental matter. The term resource efficiency is introduced instead and includes environmental issues regarding raw material extraction. It is often found that impact evaluation methods need to take into account special effects that are not of general kind, such as local environment. A special subcategory is here introduced for the safeguard human health, called comfort. This version of the SAM-method is therefore called **SAM(B), the Safeguard Assessment Method adapted to Buildings.**

The three safeguards are (for the moment) regarded as end-points, which in this case mean, that no agglomeration between safeguards should be made. However, this may of course be the practical case for internal use priority purpose, in a screening material selection process, as suggested in the EPS-system [4]. The idea of using safeguard is found in the EPS method (including five safeguards) and agglomerated by using a concept of “willingness to pay“. However, the safeguard in the EPS system is not used in practice, since the index in literature only is given as a single ranking index between different released emissions and use of resources.

3. The structure of SAM(B)

The environmental impact of buildings is often divided in a number of categories [5, 6, 7]. Two common categories are material flow and energy use. A third subcriteria introduced here is “Site specific values” and takes into account environmental themes that are equal to the difference between SAM vs. SAM(B). Material flow can be described as activities related to the building manufacturing process, construction, operation and service (heating energy excluded), maintenance, rebuilding, final demolition. Energy use for heating is here treated separately. In Sweden it is possible to buy electricity of different origin. The choice of electricity deliverer is therefore relevant for buildings with a high potential use of electricity. The environmental profile can easily change over time due to the present deliverer’s energy mix, and its environmental backpack.

Both energy use and material flow describe effects caused by the building and its utilisation. The reverse process will is also be relevant for a building - the effect from emissions realised by anthropogene or natural sources. Example of such site specific issues (that can imply great impact for the building environment) are taken into account in the building sub-category Comfort. e.g.;

- contaminated soil
- radon from ground or from building materials
- noise
- contaminated water
- indoor temperature
- ventilation
- moisture and microbiological activities

The environmental impacts given above are all related to the safeguard human health, why SAM(B) for the moment can use the standard version of the other two safeguards.

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Environmental theme for a building	Safe guards			Single score index (not recom. for public use)
	Human health	Ecological system	Resource efficiency	
Energy use	2 B	A B	IV B	Σ horizontal
Material flow	3 B	C B	III B	Σ horizontal
Site specific values	1 B	B B	VI B	Σ horizontal
Sum for the building:	Σ6 B	ΣF B	ΣXIII B	Σ vertical = Σ horizontal

Figure 1 A hypothetical example of the interface of an assessment of a building. (B in the figure indicates that a bench marking value can be found. Please note that at this point only site specific values have been established for the safeguard human health, why the figure indicates a future development).

4. The safeguards

The practical calculation of the impact assessment is here divided into two steps:

0. Inventory parameters from the inventory analysis
1. Recalculation of inventory parameters into (potential) effect categories as given in Table 1 to 3, for each building theme.
2. Calculation of the sum for each safeguard for the building.

Table 1 The structure to evaluate the safeguard human health

Safeguard,	divided in	Indicator	Effect category
human health	1. shortened life 2. comfort	1. low risk level 2. acceptable comfort level	• genotoxicity • toxic • asthmatic, allergenic and hyper sensitive • heart and vascular disorder • decease carrier • rheumatism • reduced lung function • reduced immune defence system • effect on the central nervous system (CNS) • noise • temperature • moisture level • smell (odour)

In the safeguard human health, it is possible to include aspects regarding work environment. In SAM this is missing, as well as effects by smoking and accidents. Smoking is included as smoking effect from the surrounding environment/people. It is noticed that smoking is one of the most important sources that effects the safeguard Human health today. In an evaluation method adapted to a person, SAM(P), it would be most adequate to include smoking, as well as accidents or work environment. As mentioned earlier the safeguard human health is here divided into two issues. The first one takes into account for shortened life, and the second relates to non mortal issues, here called comfort.

Table 2 The structure to evaluate the safeguard ecological systems

Safeguard	Indicator	Effect category
ecological systems	• biodiversity of fauna (and flora)	• acidification • eutrophication • ozone depletion • global warming • photochemical ozone • eco-toxicology

Biodiversity is the only indicator suggested for the safeguard ecological systems. Because of lack of data for flora the indicator biodiversity only deals with fauna. The evaluation can be made as a world wide assessment or as is done here, for a country.

Table 3 The structure to evaluate the safeguard Resource efficiency

Safeguard,	**divided in**	**Indicator**	**Effect category**
Resource efficiency	1. occupation of ground 2. substitutable	time delay for same amount of biodiversity and production space 1. environmental impact to "produce" a new material source.	• biological productivity • agglomerated effect categories effects regarding "reproduction" of raw materials

The most common way of assessing resources as areas of protection is to take into account the scarcity factor one way or other (e.g. CML and UMIP). The term "scarcity" is changing from time to time, caused by new methods of extraction, prospecting methods, market price of raw materials etc. One could ask if the scarcity is best taken into account in the society in a quite natural way by using monetary terms? Since the reserve/scarcity to be used is defined by monetary terms, resource depletion is here regarded as an non environmental issue. What is not included in a ordinary LCA is the environmental impact to recreate a resource or substitute a fossil fuel. Steen [S] has in the development of the EPS-system given figures for such evaluation. This way of treating the resource use is most adequate for the safeguard resource efficiency. Another aspect not taken into account for in a traditional LCA is the local effect of resource extraction. A method to assess occupation of ground and the time delay factor before it is as productive (measured in biodiversity) as before is discussed in an assessment method suggested by Erlandsson [9]. The assessment between the two indicators suggested for the safeguard resource efficiency, is under evaluation.

5. Discussion of result from SAM(B)

The development of SAM or SAM(B) is not yet finalised and a complete evaluation method does not exist. Since only the safeguard human health, is considered for in all three environmental themes for a building, only a specific methodology for this safeguard is given in this paper.

The basic idea how to assess the safeguard human health is partly inspired by a concept of evaluation of emissions (in general) introduced by Ahbe et al [10]. In this concept a critical level is defined and the evaluation is then made by the concept "distance to target". The method suggested here is based on a "long time low risk concentration" of hazardous substances or comfort factors. This kind of low risk levels can be found by WHO, but in this paper a Swedish work has been used [1 1]. In the equation given here the concept "distance to target" is used and then taken into account for a correction factor. The correction factor is used to give an adequate evaluation of health aspects with serious risk (fatal outcome), compared to suffering and well-being in general. All environmental impacts with fatal outcome has a correction factor equal to 1, and figures given for well-being has been reduced by a factor of 75. As comparison one could say that a lifetime of 75 years reduced by 1/75 is equal to one year.

The equation for evaluation of the safeguard human health can be described as the quotient:

$$\frac{\text{normal background concentration}}{\text{long-time low risk level times a correction factor}}$$

Note that the normal background concentration makes the index "more site specific" than is common in an ordinary LCA. This use of normal background concentration should be made by with caution. The justification of admitting this factor is that a historical site specific background has influenced life and both human, flora and fauna should have time to adapt to that situation. Another case is radiation where one could say that the natural background already is too high. By this evaluation system high background concentration is a part of "natural death" or effecting the biodiversity etc. In practise this means that we will accept more people suffering from natural radiation than from an extra exposure of toxic chemicals (in Sweden). The calculation performed so far is preliminary and given below in Table 1.

Table 1 Preliminary figures regarding human health valid for evaluation of emissions to air [11, 12 13, 14,15,16]

Substance	**Evaluation**	**Comments**
Sulphur dioxide	0,002	
Nitrogen oxides	0,007	
Particular matter (general)	0,002	
Ozone	0,0002	
Carbon monoxide	0,003	
Benzo(a)pyrene	7	
Formaldehyde	0,120	To use for indoor air quality, IAQ (= site specific value)
Toluene	0,023	
Xylene	0,041	
Benzene	6,2	
Ethylene	264	Based on background figures for only one site
1,3-Butadiene	41	
Styrene	0,003	
Dichloromethane	0,0005	
Trichloroethylene	0,0062	
Tetrachloroethylen	0,051	
Radon	0,54 (Bq)	To use for IAQ

A comparison of values given in Table 1, with an evaluation based on only a critical background level, the evaluation method given here makes in principally ozone and carbon monoxide "more hazardous", and the reverse for benzene, ethylene, B(a)P and 1,3-butadiene.

A future development of SAM(B) will hopefully be founded and published elsewhere.

6. References

1 Erlandsson, M. (1997) *Life-Time Assessment - A development of Life Cycle Assessment to implement Comparative Product Studies.* AFN, Naturvårdsverket, AFR-rapport 178, Stockholm.

2 Erlandsson, M. (1997) *Delprogram Materialflöden — En vidareutveckling av LTA-metoden.* Arbetsdokument: officiell avrapportering av etapp 1, Ragn-Sells Miljökonsult AB, Sollentuna.

3 Consoli, F. et al (Ed) (1993) *Guidelines for Life Cycle Assessment: A "Code of Practice"*. Edition 1, from the SETAC Workshop held at Sesimbra, SETAC, Portugal.

4 Rydin, S .-0. and Steen, B. (1991) *A PC-based system for development and application* ***of*** *environmental priority strategies in product design - from cradle to grave.* Swedish Environmental Research Institute, IVL, Report No A 1022, Goteborg .

5 Anon (1994) Et rammensystem for miljövurdering af bygninger. SBI, working paper, Hörsholm.

6 Anon (1996) *Økoprofil* ***for*** *bygg.* Slutrapport fra Økoprofil-utvalget. Oslo.

7 Glaumann, M. (1997) *Miljövärdering av byggnader. R&D program.* KTH, Gävle.

8 Steen, B. *(1996) EPS-Default Valuation of Environmental Impacts from Emission and Use* ***of*** *Resources, Version* 1996. Annual report, AFN, Naturvårdsverket, AFR-rapport 111, Stockholm.

9 Erlandsson, M. (1996) Ecological Valuation of Resource Extension. AB Trätek, Report L No. 9608068, Stockholm.

10 Ahbe, S. Braunschweig A and Miiller-Wenk R (1990) *Methodik für Oekobilnzen*. BUWAL, Report No 133, Bern.

11 Anon (1996) *Miljörelaterade hälsorisker.* The Government Official Reports, Offprint Report No 1996: 124, Stockholm.

12 Anon (1993) *Ett miljöanpassat samhälle. Swedish Environmental* Protection Agency, report No 42 34, Stockholm.

13 Anon (1989-93) *Kemiska ämnen (Chemical substances).* Swedish Environmental Protection Agency, Stockholm.

14 Lindskog , A. (1992) *Non methane hydrocarbons and nitrogen oxides in background air.* Swedish Environmental Research Institute, IVL, Report No A 1052, Göteborg .

15 Anon (1993) *Halter av SO_2, sot, NO_2, NO, och VOC i utomhusluft i svenska tätorter vintern 1994-95*. Swedish Environmental Research Institute, IVL, Report No L 95/188, Göteborg.

16 Anon *(1989) Miljöfarliga ämnen, exempellista och vetenskaplig dokumentation.* KEMI, Swedish National Chemical Inspectorate, Report No 10/89, Stockholm.

Wood-Assess – Systems and Methods for Assessing the Conservation State of Wooden Cultural Buildings

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Abstract
Europe's rich culture in wooden buildings are rapidly degrading due to environmental impact, wrong conservation techniques, and lack of resources and technological tools for appropriate conservation. These issues are addressed in the EU -project ENV4-CT95-01 10 Wood-Assess, and this paper summarises objectives, strategies, work-tasks and some main results from the recently finalised project. It's main objectives have been to develop and validate methods and technologies for proper assessment of the conservation state and for mapping and assessing environmental risk factors and -areas to wooden buildings on macro, local and micro-scale. The systems and methods have been validated by assessing chosen buildings in Germany, Sweden, Norway and Poland. Main work-tasks have been the development of an assessment protocol and a field inspection system, of the WETCORR method for continuos monitoring of temperature and moisture in the micro-environment on and within wood, and of a system for mapping the rotting index for wood on various geographical levels by the use of existing climatic data, standards and the WETCORR measurements. The assessment system, which allows for maintenance management is available in a PC-based geographical information system, GISWood.
Keywords: wooden buildings, condition survey, assessment protocol, mapping environmental risk factors and -areas, geographical information systems (GIS).

1. Introduction

Europe's rich culture in wooden buildings are rapidly degrading due to environmental impact, wrong conservation techniques, and lack of resources and technological tools for appropriate conservation.

There are 2.4 million timber-framed buildings in Germany. Most of them erected before 1870 (79%). Norway has 2500, and Sweden 800 wooden buildings that have been listed for conservation. To this must be added the logged-timber buildings in Upper-Bavaria and the Black Forest, and also the "Umgebinde" buildings in eastern part of Germany, and in Poland and the Czech Republic. Also in central and southern part of Europe there are a lot of timber- framed houses.

Wood is also an environmental friendly, but scarce, material which today should have a potentially much wider use. In that respect better systems for its protection should be developed.

The Wood-Assess project pursues pooling of European resources to develop methods and technologies for proper -assessment of the conservation state and for mapping and assessing environmental risk factors to wooden cultural buildings. This will facilitate a more sustainable management.

2. Model for degradation of wooden materials and objects

The degradation of outer parts of wooden buildings are influenced by a whole set of factors, see Figure 1, such as environmental degradation agents classified here according to IS0 6241 (1), quality of wood and the type of and quality of wood protective treatment, maintenance and so on.

The relationship between the environmental degradation agents and the observed effects are expressed as dose-response functions. Due to the very complicated nature of the degradation system and a lack of systematic scientific research, very few quantitative dose-response functions exist today. Scheffer's Climatic Risk Index (CRI),

$$CRI = \frac{\sum_{Jan.}^{Dec.}\left[(T - 2)\ (D - 3)\right]}{17} \qquad (1)$$

which describes the rotting tendency of wood as function of climatic parameters of temperature and moisture, is an example of such functions (2). A main objective of the project is to develop and validate such an index for the chosen locations.

Further, when looking at building elements and the whole building, factors such as constructive solutions, micro environment at the building, workmanship and the time aspect, i.e. the history of the building becomes essential.

Information on all these elements needs to be elaborated in a systematic way, as does also the methodology for carrying out the condition assessment survey including the field inspection.

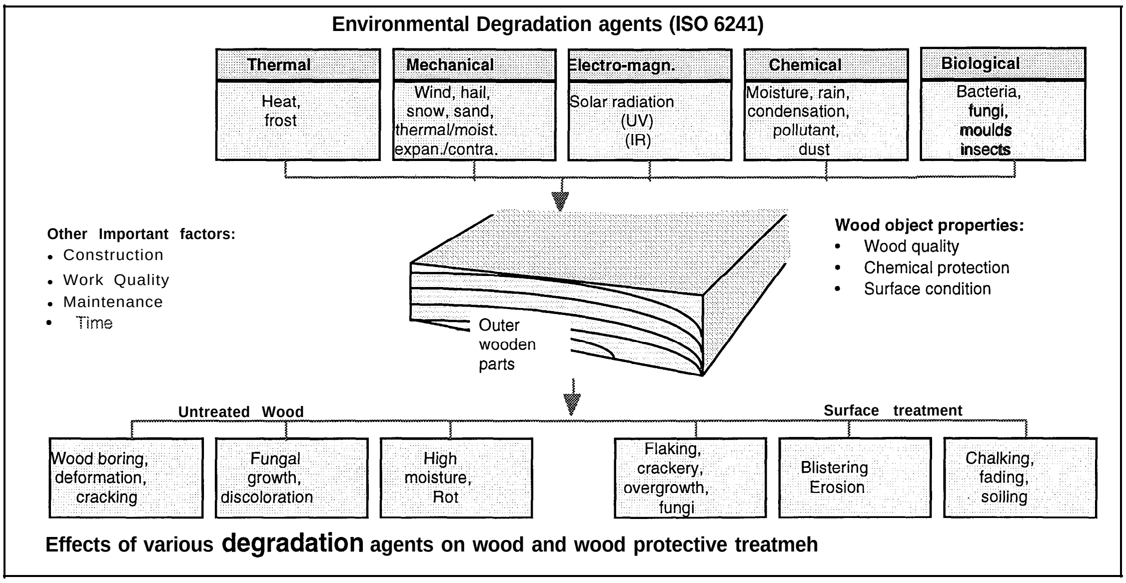


Fig 1 Degradation of wooden objects – model of degradation factors and their observed effects.

3. Project objectives and strategies

Objectives are to *develop and validate:*

1. *Systems and methods for assessing the conservation state for the outer wooden parts of cultural buildings, and their causes and effects.*
2. *Methods for measuring continuous surface time **of** wetness and resulting moisture content inside wood, biological and environmental damage to wood.*
3. *Methods **for** assessing and mapping environmental risk factors and areas **for wood** on meso- and micro- scale at some locations in Europe.*

The systems and methods are validated by assessing outer wooden parts of chosen buildings in Germany, Poland, Norway, and Sweden. Locations and types of houses are characterised as follows:

Germany:
Ebersbach – inland climate, originally agricultural and for many years industrial emission. *“Alte Mangel”* - German “Umgebindehaus” (logged construction in ground floor and timber frame above) built between 1767 and 1770.

Poland:
Swidnica – dry inland, heavy industrial pollution, object *“Peace church **of** the Holy Trinity”*, timber-frame construction built between 1656 and 1657.

Norway:
Maihaugen – House *“Hjeltarstua”* is situated on Skjåktunet at Maihaugen open air museum in the outskirts of Lillehammer. The house, which was built in 1763, is a log

house with log loft on the east part of the house. It was moved to Maihaugen around 1905.

Sweden:
Gävle – urban coastal, cold climate. House *"Berggrenska Gården"* is situated in the centre of the city. It was built in 18 13 and partly rebuilt in 1869,
Stockholm – urban, cold, climate. House "*Norrkulla gård*" is situated north-east of the centre of Stockholm at Waxholm. Cabin built of logs dovetailed at the corners, outer vertical boarding. Ground floor built between 1750 and 1800, and the second floor built after 1850.

4. Results

4.1 PC based assessment protocol and field inspection system

The Assessment protocol is synthesised from existing national guidelines and standards in the participating countries (3). The protocol is available in a PC-based geographical information system (GIS), see Figures 2 and 3.

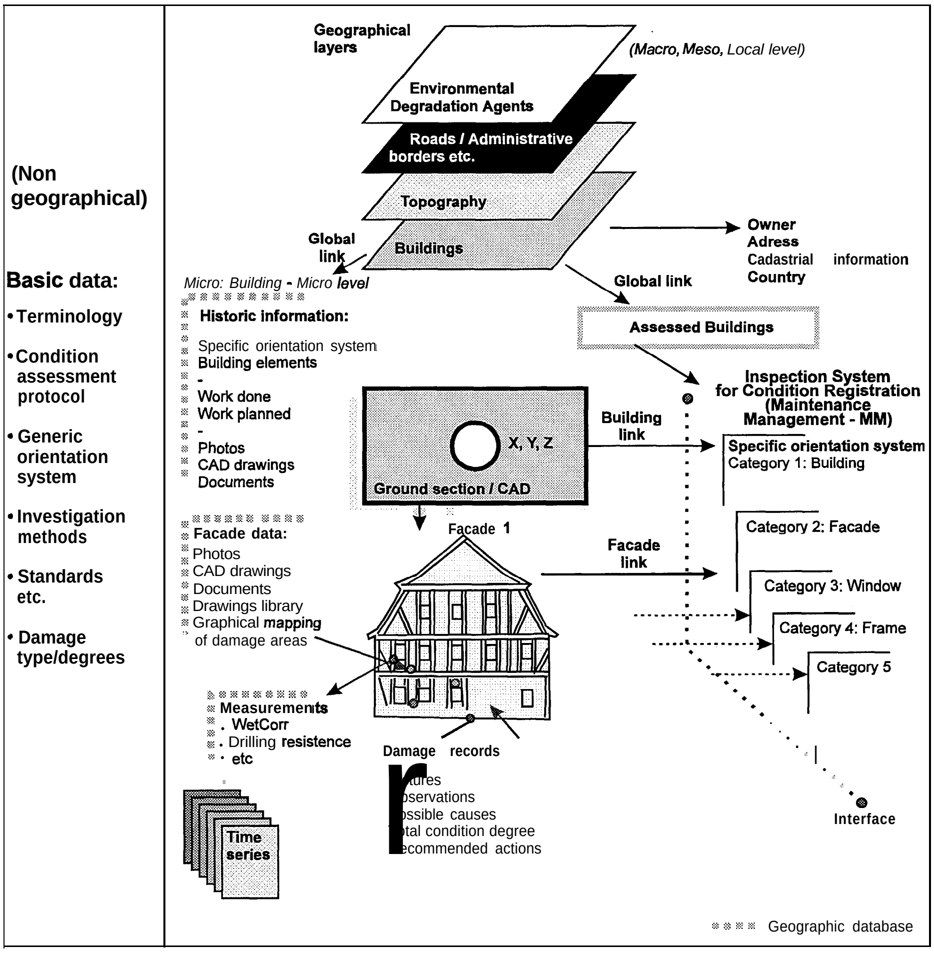


Fig 2 Schematic view of integration of information and information elements in GISWood.

Figure 2 shows a schematic view of levels of information and information elements in GISWood, such as

- Building orientation system;
- Description of purposes, phases and levels of investigation;
- Overview of investigation and measuring methods;
- Themes for environmental risk factors;
- Databases with types, degrees, causes and effects of damages (Pictures and texts);
- System for graphical mapping of damages.

This system will give the user a tool to handle and systematise data from the assessment of cultural wooden buildings. This ranges from needed basic background data and knowledge down to detailed measurement and inspection data. Different user levels are taken into account (3).

The Wood-Assess – GIS system is based on the standard ArcView 2.1 package, which is a part of the ARC/INFO GIS system, delivered by ESRI. ArcView is Windows based program running under MS-Windows 3.1, Windows 95 and Windows NT.

Figure 3 shows the assessment and categorisation of some damages at Hjeltarstua, Maihaugen, Norway as recorded by the inspection system, MMWood and exhibited in the GISWood system.

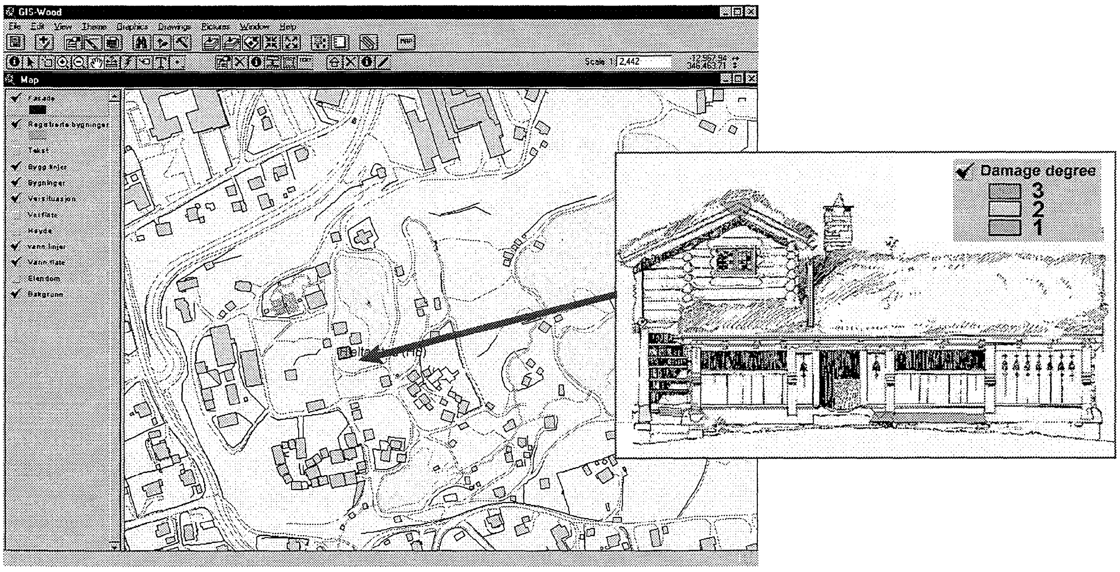


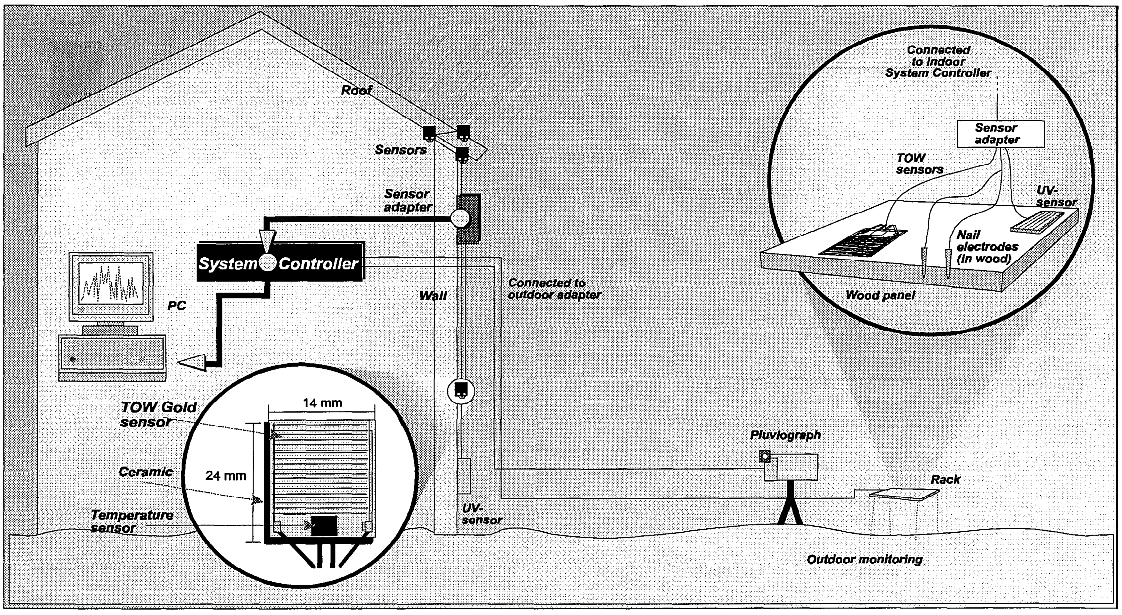
Fig 3 Damage assessment of Hjeltarstua at Maihaugen, Lillehammer exhibited in GISWood.

MMWood is a computer-based system developed in order to structure the work and the resulting information handling from inspections, and also as a tool easing the planning and execution of maintenance work.

The inspection is done by using a handheld computer with a bar-code reader and a digital camera for taking pictures. The bar-codes are defined in the assessment protocol, and consists of categories of elements of a wooden building, observations of symptoms linked to these elements, and a set of predefined questions ensuring the proper registration of relevant information.

4.2 Measuring moisture and temperature on and within wood

Measurement methods for moisture and temperature in the micro environments are based on the NILU WETCORR measuring device (4). The existing gold sensor measures surface moisture and -time of wetness, while nail electrodes is developed into a new sensor application, WETCORR INWOOD, for continuously measuring the uptake and distribution of moisture within wood. This has been performed both in laboratory measurements in climate chambers and in field at the chosen locations (5). The monitoring set-up in field is shown in Figure 4 , and the results are described by Eriksson (5).



a) b)

Fig 4 a) WETCORR instrument with gold (Au) sensors for monitoring Time of Wetness (TOW) and temperatures, and sensor for measuring critical UV-radiation, at various places on buildings. b) Climatic Risk Index assessment at location of house. Pluviograph for precipitation and Wood sample with Au sensor for surface TOW and nail electrodes for moisture inside wood (INWOOD), and sensor for critical UV-radiation.

4.3 Assessing and mapping environmental risk factors

There are great differences in temperatures and precipitation regimes in Europe. This results in equally great differences in potential wood decay rates.

The assessment of Environmental risk factors were assessed by calculating Scheffer's climatic index for potential wood decay from existing meteorological monthly data for temperature and duration of precipitation at the chosen locations, and on measurements of selected climatic variables at one site on each location, see Fig 4. By comparison with the WETCORR data for wetness duration and temperature, this climatic risk factors can be transformed to a WETCORR based Climatic Risk Factor (6).

This formula will be specific for each type of wood, and opens up the possibility of continuous moisture characterisation of various types of wood. To map the CRI in the micro environment on the building, WETCORR measurements are performed on the critical points of the assessed buildings. By comparison of these data with the open exposure data, relationship between the local incoming climatic moisture and the resulting micro-climatic moisture on and within wood parts of the buildings is obtained. This will be major new methodologies and tools for assessing the climatic risk factors for wood preservation on meso-, local- and micro scale in Europe, which can have broader implications also for the building sector in its implementation of the Construction Products Directive (7).

5. Conclusions

Common guidelines for documentation and assessment of condition state of outer wooden buildings have been developed, based on documentation and evaluation of damage causes, effects, consequences, risks and possible remedial actions. The assessment protocol also contains modules for assessing the environmental risk factors and is available on a PCIGIS based platform.

6. References

1. Scheffer, T.C. (1970) A climate index for estimating potential for decay in wood structures above ground. *Forest Products Journal,* Vol. 21, pp. 10-25.
2. Norberg, P. *Evaluation of a new Surface Moisture Monitoring System.* 6th Int. Conf. on Durability of Building Materials and Components. 26-29 October 1993, Omiya, Japan.
3. Haagenrud, S .E. (1997) *Environmental Characterisation including equipment for Monitoring. CIB W80/RILEM 140-PSL, SubGroup 2 Report,* NILU, Kjeller, NILU OR 27/97
4. Veit, J. *An assessment protocol for historic wooden buildings.* CIB World Building Congress 1998, Gavle, Sweden, 7-12 June.
5. Eriksson, B., Norberg, P., Noren, J., Elvedal, U. and Henriksen, J.F. *Development and validation of the WETCORR method for Continuos monitoring of surface time of wetness and the corresponding moisture content in wood.* CIB World Building Congress 1998, Gavle, Sweden, 7-12 June.
6. Henriksen, J.F., Haagenrud, S.E., Elvedal, U., Norberg, P. and Veit, J. *Wood-Assess - Mapping environmental risk factors on the macro-, local and micro-scale.* CIB World Building Congress 1998, Gavle, Sweden, 7-12 June.
7. Noren, J. (1998) *Service life prediction of buildings and the need for environmental characterisation and mapping.* CIB World Building Congress 1998, Gavle, Sweden, 7-12 June.

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Ecological aspects of using concretes with large-tonnage waste

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Abstract

Great attention is currently being paid to destructive effects of industrial activity that in certain countries has been known to disturb the balance of nature. Construction ecology deals with the utilization of large-tonnage waste accumulated in industrial disposal areas. Large-tonnage waste (LTW) occupies vast territories of land, increases man-made environmental effects, and thus adversely affects human health in general. The construction materials industry holds a unique pACLe within this context. The use of LTW in the construction industry can solve the three-pronged problem of reducing the cost of construction materials, saving natural raw materials, and protecting the environment. LTW contains many harmful impurities including heavy metal compounds. So, waste can be utilized to advantage only if both the technological and ecological-health properties of waste and building materials are taken into account. The authors of the paper jointly with the Research Institute for Ecology of Man and Health of the Environment (RIEM&HE) have determined the ecological-health properties and characterized the level of danger of man-made waste and of hardened cement paste based on low-clinker binders and various concretes containing acid ash. The study has shown that the toxicological problem of man-made wastes and of construction materials on their basis does exist. However, in spite of the fact that individual waste materials may be harmful, man-made waste combined with traditional construction materials can be used to manufacture ecologically benign materials. This is because hardened cement paste and concrete can fix harmful ingredients in place both by drawing them into hardening process and by making them part of the structure of hardened cement paste.
Keywords: concrete, large-tonnage waste, heavy metals, toxicity, ecology.

1 Introduction

Great attention is currently being paid all over the world to destructive effects of industry that disturb the balance of nature [1]. Modern ecology has split into a considerable number of specific areas. What is known in Russia as "construction ecology” deals in particular with the utilization of large-tonnage waste (LTW) that has accumulated at dumps occupying huge land areas. This in turn has increased the man-made environment loads that consequently produce a considerable adverse effect on human health.

The construction materials industry holds a unique pACLe within this context. The use of LTW in the construction industry as valuable secondary mineral raw materials can solve the three-pronged problem of reducing the cost of construction materials, saving natural raw materials, and protecting the environment.

Large-tonnage waste can be used most efficiently in the production of the binders that do not need much energy to manufacture, of aggregates, and of various types of concrete since in this case the best cost effectiveness can be ensured and competitive materials can be produced.

High technological compatibility between man-made waste and natural materials, including Portland cement, is due to the affinity of the elementary composition which mainly consists of oxides, including SiO_2, Al_2O_3, Fe_2O_3, and CaO and, in small quantities, MgO, SO_3, MnO, Na_2O, and K_2O. The difference between man-made waste and natural raw materials lies only in quantities of these oxides.

Together with basic oxides, natural and man-made raw materials contain small amounts of impurities that can be divided conventionally into technologically harmful and ecologically harmful agents. The content of the technologically harmful impurities that adversely affect the engineering properties of concretes, binders and aggregates and reduce their durability is quoted in all specifications.

Ecologically harmful impurities are toxic elements and these include primarily the compounds of heavy metals, such as Pb, Ca, Co, As, Cu, Zn, Ni, Cr and Mg; and toxic substances and carcinogens which were not considered harmful in the past. In Russia, it is only in the last few years that radioactivity of man-made waste that is being checked due to the publication of GOST 30108-94.

Table 1 lists typical ranges of contents of heavy metals derived from ashes of cogeneration plants (CGP) in Russia. The data were reported by the Resource Research Institute. Table 1 shows that contents of individual elements in ash can vary by an order of magnitude from **3** to 10.

Table1 Content of heavy metals in ashes of coals from main deposits in Russia.

Element	Cd	co	cu	Ni	Pb	Zn
Content g/ton	**2.5-24**	**30-85**	**25-246**	33-194	**64-224**	**87-267**

It can be seen then that wastes can be utilized to advantage only when, in addition to technological properties and performance in construction, the ecological-health properties of the waste and of building materials they are part of are taken into account. Thus secondary pollution can be avoided and ecologically clean dwellings can be built.

The most important industrial waste for construction is the waste of power plants, of the metallurgical industry, and of the chemical industry. These include wastes such as ash and ash-slag mixes, metallurgical slag and sludge, and sulphate-bearing production waste.

The distinctive characteristic of metallurgical and power plant wastes is their capacity for sulphate, alkali and other types of chemical activation of waste from other industries, including sulphate-bearing materials, both natural and man-made. We applied this principle to develop a new type of a low-clinker composite binder based on sulphate-bearing materials of natural or man-made origin (e.g. phosphogypsum-dihydrate) and on acid ash from cogeneration plants, which mutually activate hardening. This binder was developed with a Portland cement content of up to 30% by weight. The binder is hydraulic, water-resistant and has a normal setting time. The strength of hardened cement paste varies from 15 to 45 MPa. Fine-aggregate concretes made with this binder and ash-slag mixes as fine aggregates are equivalent to the concrete strength grades of B7.5 to B20, Portland cement content being 50 to 100 kg/m^3.

In collaboration with the Research Institute for Ecology of Man and Health of the Environment we have determined the EH properties and the level of danger of man-made waste and hardened cement paste with low-clinker binders and various concretes containing up to 600 kg/m^3 of acid ash.

2 Investigation procedure

We used accelerated methods developed by the Research Institute for Ecology of Man and Health of the Environment [2] to evaluate the EH properties. The principal stage of this test procedure is a biological-chemical analysis of multicomponent industrial waste. Along with the chemical analysis, the level of biological activity of waste specimens was investigated. The presence of mobile forms of heavy metals in the wastes served as an indication of the biological activity. The quantities of heavy metals vary over a wide range depending on the acid-base equilibrium in the environment of the waste. So the content of heavy metals was determined in tap water (pH 7.0 to 7.2) and in an acetate-ammonium buffer solution (pH 4.8). The analysis and comparison of heavy metal contents in these extracts enabled us to predict the level of danger of a particular waste material.

The buffer extract can simulate the acidity of soils and the effects of acid rains thus making it possible to evaluate adverse effects of wastes when they enter the soil or are affected by an acid rain. The comparison between the heavy metal contents in the water and in the buffer extracts of the waste and their allowable concentration limit (ACL) for soil and water ponds permits the evaluation of the level of potential danger of the waste for the environment.

Together with the biological-chemical analysis, criteria were developed and a method for evaluating the danger of metal-contaning waste by accelerated biotests (a biotest for germinating seeds and biotesting by means of water organisms of infusoria and daphnia) was substantiated by experiments.

The terms “ecologically clean materials” and “ecologically clean dwellings” have become quite common in the last few years. The basic governing documents currently in use for the ecological-health (EH) evaluation of a material or a medium are allowable concentration limits (ACL) of contaminants for various media. It can be said with assurance that a construction material is ecologically clean if the release of ecologically harmful substances from the material does not exceed the ACL for free air, soil and water ponds.

The procedure for investigating specimens of hardened cement paste based on low-clinker binders is as follows. The migration of substances from the material to the air was tested in special accumulating chambers. Specimens of the material having the same composition were placed in the chamber for 24 hours and then air samples were taken. Air was sampled again in the chamber after 10 and 30 days, and changes in the migration of harmful substances into the air were determined. For comparison, the same tests were made for specimens of construction materials that did not contain any wastes (control specimens).

The investigations in the chambers were conducted at temperatures of 20^0C and 40^0C. Various air flows varying from 0.02 m/s (indoor service conditions) to 1.5 to 5 m/s (street conditions) were simulated to produce the effect of wind erosion on the material under study and to take air samples to check for accumulated dust. The dust was then subjected to chemical analysis to determine the content of harmful ingredients.

Since the density of hardened cement paste and of concrete specimens is very high and the migration of chemical substances to the air is relatively low, the during the EH investigations we were able to study the degree of migration of chemical substances from building materials under the action of real-life situations such as acid rains (for certain types of buildings), seasonal temperature differences, or deterioration of a material. The best way to simulate such conditions is the investigation of water extracts from construction material specimens that have insignificant spallings from surface, thus simulating some damage to the material.

Water extracts from construction materials should be also tested where they may be in contact with water that can dissolve their components, including the compounds in the waste used in a material, which thus can get into ground water.

To study the migration of harmful substances to water, specimens of construction materials should be placed in tanks filled with distilled water. The ratio of the volume of the material to that of water depends on the intended use of the material. When the contact with water is of short duration and not permanent (e.g. walls of houses or roofs), this ratio is 1: 10. If construction materials are used in long-term and permanent contact with water (e.g. foundation blocks, road slabs, piles, and elements of hydraulic structures), the ratio is increased to 1:2 or 1:3.

Water extracts were tested in 1, 3, 7, 10, 20, and 30 days of water immersion in a bath of 20^0C and 40^0C characteristic temperature of dwellings in summer.

3 Results and discussion.

The EH properties of the following materials were investigated:

- ash of two cogeneration plants (i.e., from their dumps);
- phosphogypsum-dihydrate from the Voskresensk cement factory (i.e., from its dump);
- Portland cement;
- hardened cement paste (FGC-70, FGC-30, AGCB, see below);
- concretes containing ash (i.e., normal-weight concrete, fine-aggregate concrete, and lightweight concrete);

The first type of the hardened cement paste specimens (FGC-70 and FGC-30) contained fine cements containing 70% and 30% ash and 30% and 70% Portland cement, respectively. The second type of the specimens (AGCB) was based on fine ash-gypsum-cement binder that contained 40% ash, 40% phosphogypsum-dihydrate, and 20% Portland cement.

The total content of heavy metals was found by mass spectrometry. The content of the metals in mobile form in water and in acetate-ammonium extracts was determined by the atom-adsorption method and by the spectrophotometric method.

The research results are given in Table 2. One can see from this Table that the wastes had in their composition harmful ingredients such as Cd, Co, Cu, As, Cr, Zn, etc. The total content of these elements in some wastes considerably exceeded the allowable concentration limit (ACL) for soil. So, these wastes could be classified as potentially dangerous. The analysis of the content of water-soluble forms of heavy metals found their largest quantity in phosphogypsum (Cu, Ni, Zn) and in the ash from the Severodvinsk cogeneration plant. So we could say that these wastes were biologically active.

Table 2 Content of heavy metals (gross and flowing forms) in various types of waste

Waste type	Content of elements	Cd	Co	Cu	As	Ni	Pb	Cr	Zn
Dsposal ash CGP-22	total, mg/kg	2	19.6	14.5	16.5	-	9	180.3	16.4
	water extract mg/l	0.001	0.01	0.01	.015	0.01	0.01	0.01	0.01
	extract in buffer solution, mg/l	0.001	0.01	0.12	0.091	0.01	0.01	0.18	0.46
Ash from Severodvinsk CGP Sample 1	total, mg/kg	2.9	59.4	87	59	213	2.3	704	115.5
	water extract mg/l	0.001	0.01	0.01	0.04	0.01	0.01	0.01	0.01
	extract in buffer solution, mg/l	0.001	0.06	0.31	0.6	0.19	0.01	0.3	0.3
Ash from Severodvinsk CGP Sample 2	total, mg/kg	1.5	10	40	-	40	5	9	16
	water extract mg/l	0.03	0.05	0.04	-	0.06	0.1	0.02	0.03
	extract in buffer solution, mg/l	0.6	1.0	2.8	-	4	-	1.4	3
Phosphogypsum dihydrate from Voskresensk factory	total, mg/kg	2	227	126	-	7.5	2	7.1	185
	water extract mg/l	0.001	0.01	1.37	.0004	0.13	0.01	0.01	1.24
	extract in buffer solution, mg/l	0.001	0.03	1.3	.0004	0.16	0.01	0.01	1.35
Portland cement without admixtures	total, mg/kg	2	7.4	16	2	11.3	2	119	35
	water extract mg/l	0.001	0.01	0.01	.0004	0.01	0.01	0.01	0.01
	extract in buffer solution, mg/l	0.001	0.01	0.02	.0004	0.01	0.01	0.32	0.01
Allowable content limit in soil (ACLs), mg/kg		0.5	50	33	2	20	32	90	55
Allowable content limit for water ponds (ACLwp), mg/l		0.001	0.1	1.0	0.05	0.1	0.03	0.5	1.0

Table 2 shows that the quantity of mobile forms of metals in the buffer solutions increased significantly for all wastes as compared with the water extract. In some cases it substantially exceeded ACL for water ponds.

The Laboratory for Industrial Waste at the RIEM&HE (Moscow, Russia) have investigated the wastes and established their level of danger. It was found that the waste under study fell into the category of highly dangerous materials. These findings are rather doubtful. The level of danger thus established puts these wastes in the same group with really harmful waste such as galvanic sludge. It means that the experimental procedure when used regardless of the actual application of waste should be adapted to the specific use of waste in the production of building materials.

We should emphasize that it is very important to determine correctly the level of danger of a particular material. Groundless overrating or underrating of the danger level of industrial waste can only have negative consequences. The former will complicate application and reduce the quantities of waste in the production of construction materials while the latter will be evidently dangerous for human health.

The results of studying the EH properties of hardened cement paste specimens containing the fine low-clinker binders FGC-70 and AGCB that emit harmful substances to free air are shown in the diagram (Fig. 1) in terms of ACL units.

$$C_i \text{ (in ACL units)} = C_i / ACL$$

where C_i is the concentration of the i-th element released from the specimen to the environment.

It is evident from these results that the EH properties of hardened cement paste with AGCB differ considerably from those of the cement paste with FGC-70. In the case of the AGCB hardened cement paste, the release of heavy metal compounds into the air is substantially lower than the ACL (see Fig. 1).

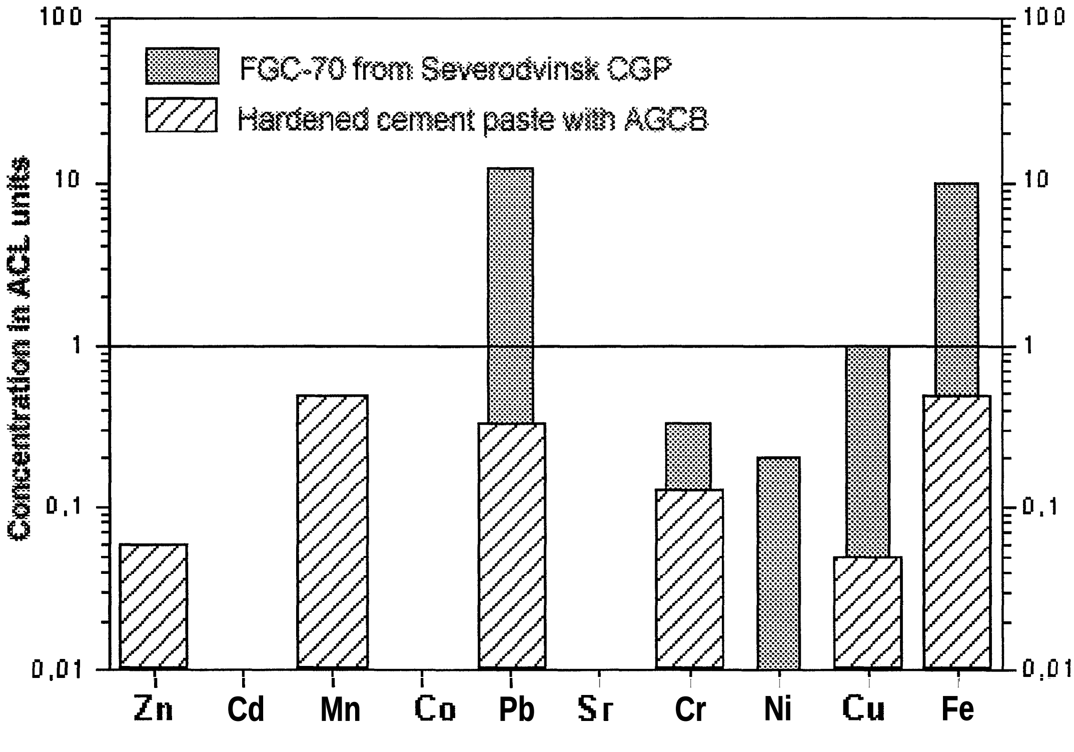

Fig. **1**

In addition, the research results showed that water extracts from ash-gypsum-hardened cement paste did not contain any water-soluble compounds of Cu, Zn, Ni, and

Mg which were found in water extracts from phospho-gypsum. This points to the fact that hardened cement paste can “absorb” harmful ingredients present in industrial waste.

Ecological-health properties of various concretes (i.e., normal-weight concrete, fine-aggregate concrete, and lightweight concrete) that contained disposal ash from the CGP-22 were studied. The investigations demonstrated that specimens of normal-weight concrete (ash content 350 kg/m^3), of fine-aggregate concrete (ash content 500 kg/m^3), and of lightweight concrete (ash content 350 kg/m^3) do not emit harmful ingredients to the air and water. Thus, it may be said that these materials are essentially clean ecologically.

Conclusion

On the strength of the above data obtained we can draw the following conclusions:

- The problem of toxicity of man-made wastes and of their products does exist and the research results confirm it.
- Man-made waste combined with traditional construction materials can be used to manufacture ecologically benign materials. This is because hardened cement paste and concrete can fix harmful ingredients in place both by drawing them into hardening process and by making them part of the structure of hardened cement paste.
- The regulations currently in use do not contain any approved single procedure for evaluating EH properties of man-made wastes and the construction materials derived from them;
- It is essential that approximate methods should be developed to evaluate the EH properties of man-made waste and of construction materials;
- These methods need to be related to the peculiarities of using industrial waste in the construction industry and the subsequent service conditions in which the materials will be placed.

5. Acknowledgements

The authors thank N.V.Kalinina, N.V.Rusakova and N.I. Tonkopi (RIEM&HE, Moscow, Russia) for helping complete the experiments and the many fruitful discussions and I.G. Scheblykin for remarks and correction of the text.

4 References

1. The ecological-health aspect of the problem of heavy metals as a man-made contaminating agent. (199 1) *Republican Interdepartmental Collection of Papers*, Kiev (in Russian).
2. Rusakov, N.V., Tonkopy, N.I. Methods for evaluating soil and industrial waste (1996). *Ecology of Man*, No. 3 (in Russian).

Experimental program to evaluate building components service life: an application

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Abstract

The knowledge of the service life of building materials and components is a basic requisite in order to correctly compare global costs (manufacturing cost, maintenance cost, recycling or demolishing cost) of different building components. It is also recognized that the best way to obtain the actual service life of materials and components is to analyze statistical data from existing buildings, but the observation of existing buildings requires a lot of both economical and human resources that are not easily found. This paper intends to give a contribution in the field of building materials durability showing principal intermediary results obtained from ongoing research by the Polytechnic of Milan. This project is in association with an Italian industry leader in coil coated steel sheet manufacturing. The results presented in this paper are part of one of the first test application of a methodology elaborated at the DISET - Polytechnic of Milan to evaluate building components service life. In particular, results will be presented from surveys on existing buildings built from 1985 to 1996 and from three years atmospheric environmental exposure tests conducted both in Italy and in Holland.

Being results obtained from a test application they have been useful to tune the methodology and to gain knowledge in the field of coil coated steel sheet durability.

Keywords: Building products, coil coated steel sheet, exposure test, service life, survey.

1 Introduction

The solution of the problem of sustainable development in building sector passes through the individuation of some priorities in the choice of the materials to be used in the design and the production of building components. The choice of these materials must take into account their compatibility with the global equilibrium of use of natural resources. This compatibility can be expressed as the global cost (manufacturing cost, maintenance cost, recycling or demolishing cost) of the material itself. Therefore only materials for which this compatibility is recognised, i.e. those materials which minimise the global cost function, should be taken into account for an environmental conscious building process. The architects and the maintenance managers could make the right choice, i.e. reduce the environmental impact of the building, only if they could evaluate this global cost. It is recognised that the right value of the service life and the reliability of this value are a basic requisite in order to correctly compare global cost.
At the DISET - Polytechnic of Milan researches on these subjects started more than ten years ago and, at the present time, have produced a methodology to evaluate reliability of a certain value of service life by the functional analysis (the paper "*Functional analysis as a method to design new building components*" presented in this congress shows some of the results achieved in this field) and a methodology to evaluate building components service life (the paper "*Methodology and experimental program to evaluate building components service life*" presented in this congress explains the methodology and shows first experimental results). This paper presents some of the results achieved in the first phase of the research on building components service life.

2 The methodology

The goal chosen for the research at the DISET was to evaluate the durability of a set of seventeen building components for exterior wall without considering, in the first time, the connection between components. The methodology, although defined in its main characters, is still subjected to little changes according to what comes out from the ongoing experimental program and from the studies of our research group.
Some main steps can be found inside the proposed methodology. These steps, with the exception of minor changes due to the evolution of the research, seem to be definitive. One of these is the step that comes out with the evaluation of building products sensitivity that is essential in order to evaluate building components service life according to our methodology. The step that describes how to compute building product is one of the most tested of the whole methodology and has been already presented in an Italian congress [1].
The evaluation of building components sensitivity, if they are imagined to be exposed directly to aging agents, can be made following these scheme:

- definition of the aging agents relevant for the building product under evaluation;
- collection of bibliographical information;
- computation of building product sensitivity;

2.1 Definition of the aging agents

One of the first results of the research was the definition of a set of aging agents to which the evaluation of building components behavior over time can be referred. It stands to reason that durability of building components changes according to the different environment (i.e. aging agents) in which they are used. Since it is possible that different building products are influenced in their behavior by different agents, the set defined has been used as a base point in order to create a subset of aging agents relevant for the specific product. Table 1 shows the set of agents, the ones relevant for coil coated steel sheet are highlighted by a "*x*". The set of agents here quoted has been defined joining indication of some Italian and foreign standards (English and American)[2][3][4].

	Set of aging agents	
Chemical agents	CO_x	x
	NO_x	x
	SO_x	x
	Sulfuric acid	
	Carbonic acid	
	salts	
	Cleaning products	
Weathering agents	Moisture	x
	Rain	x
	Snow	
	Ice	
	Hail	
	Water vapor	x
	Wind	x
	Air pollutants	x
	High temperature	
	Low temperature	
	Temperature cycle	
	Solar radiation	x
	Thermal radiation	
External artificial agents	Electromagnetic radiation	
	Discontinuous mechanical stresses	
Artificial agent due to use	Cleaning water	
	Continuous mechanical stresses	
Biological agents	Animals	
	Vegetable	

Table 1: The main set of agents and the ones considered for coil coated steel sheet

2.2 Collection of bibliographical information

Collecting data on behavior over time of building products that form the set of building components under analysis has been an essential step in the development of the research. The results of this phase have been stored in filling-cards in order to have an easy to read documents. Each filling-card describes one action, i.e. the consequence of one or more agents on the building product. The cards are divided in fields describing possible effects of the action and chemical or physical phenomena that lead to the effects. Unfortunately there aren't information or studies on every possible action on building products and on the consequences of these actions, especially for innovative products. As a consequence of this lack of information we felt necessary to gain further data through specific test programs and surveys on existing buildings. For this reason we joined an Italian industry leader in coil coated steel sheet manufacturing, La Magona d'Italia S.p.A., which kindly allowed us to publish results obtained from:

- quality control tests on new products conducted in their factory;
- atmospheric environmental exposure tests;
- survey on existing buildings built since 1985 with their coil coated steel sheet.

3 Atmospheric environmental exposure test results

Among the results obtained by the cooperation between DISET and La Magona d'Italia we can count those concerning atmospheric environmental exposure of coil coated steel sheet samples with different kind of coating. Samples with three different kind of coatings and painted with two different colors, light the first and dark the second, have been exposed for three years in two different places. The first exposure place is in Italy, in the nearby of the factory, the second is in Holland by the North Sea.
The three coatings differ for their resistance to the atmospheric agents, because of a different composition of the coating layer. In particular the manufacturer assures his products to have a color difference from the new ones less than 8 Celiab units (ECCA T3 [5]) and a chalking value (ASTM D659) higher than 6 after 10 years for the product called system 3000/90, after 15 years for the product called 5000/90 and after 20 years for the product called system 10000/90. The two different colors have been chosen in order to highlight eventual discoloration phenomena that are generally more emphasized on dark pigments. The following parameters were recorded:

- *D Gloss*: the gloss of a sample is measured by the amount of light reflected from a specimen in the specular direction. The shift value is reported as a percent value of the original gloss;
- *Scratch* or edge: rust penetration either through a cut on the coating layer or from the edge where the steel sheet is cut is measured. The value is reported as a percent value considering a penetration of 10mm as 100%;
- *6mm hole*: rust penetration from the edge of a 6 mm diameter hole is measured. The value is reported as a percent value considering a penetration of 10mm as 100%;
- *Bend 0-T*: this test comprises bending the sample through 180" over a period of l-2 seconds around various radii. The value reported is the percentage of defective surface;
- *Erichsen 6mm*: coil coated steel sheet are subjected to ball punch deformation. The value reported is the percentage of defective surface;
- *Dust retention:* The value is reported as a percentage considering the value 10 measured according to ASTM D3274 as 100% and the value 0 as 0%;
- *Chalking:* The value is reported as a percentage considering the value 10 measured according to ASTM D659 as 100% and the value 0 as 0%;

- *Blistering*: The value reported is the percentage of defective surface evaluated according to ASTM D714

Unfortunately it wasn't possible to report the same aging parameters both for the Italian samples and for the Dutch ones because the exposure tests in Italy began before the exposure tests in Holland and followed test methodologies based upon Italian standards, while in the Dutch tests the European Coil Coated Association standards were followed.

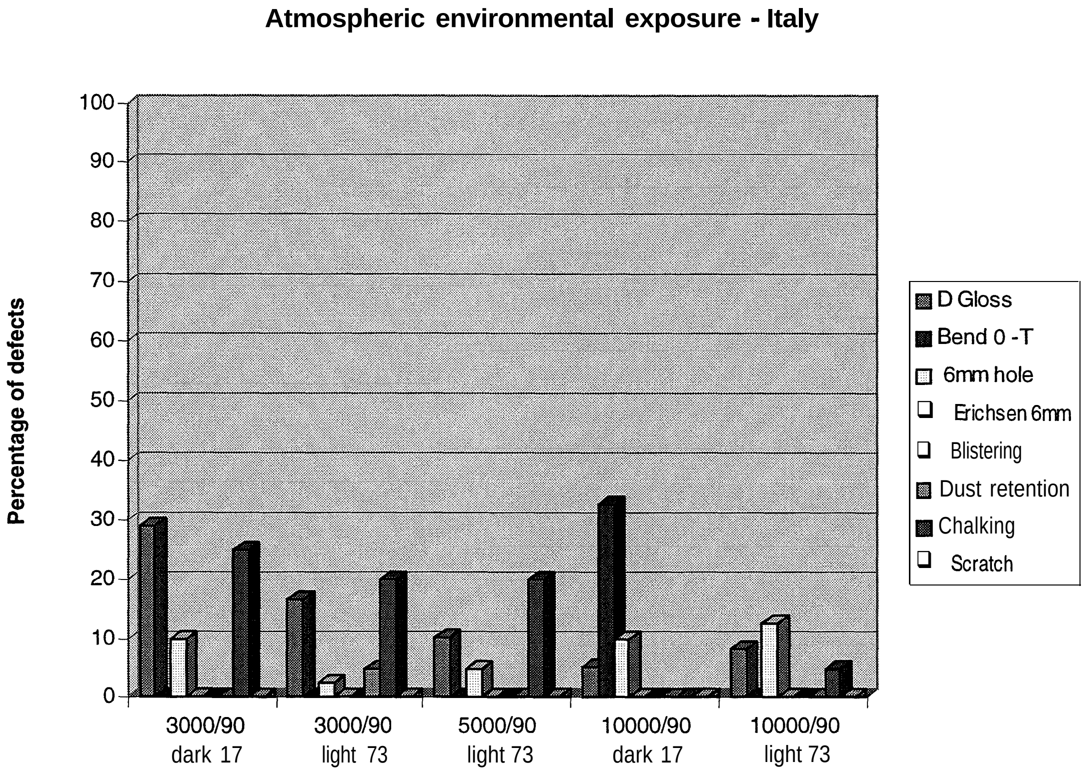

Figure 1: Results after 36 months of exposure in Italy

Examining the results after 36 months of exposure in Italy (Picture 1) we can see that the principal defects are a generalized loss of the initial gloss, some chalking and rust attack on the edge of the 6mm diameter hole. The loss of initial gloss detected in Italy is higher than the one measured for the samples exposed in Holland and is due to the high level of air pollution caused by dust. It is possible that this kind of pollution, maybe due to the presence of steel-plants in the nearby, faked the values measured, hiding the correlation between the loss of gloss and the color of the sample. This correlation can be seen in the values obtained for the samples exposed in Holland where there was less air pollution.

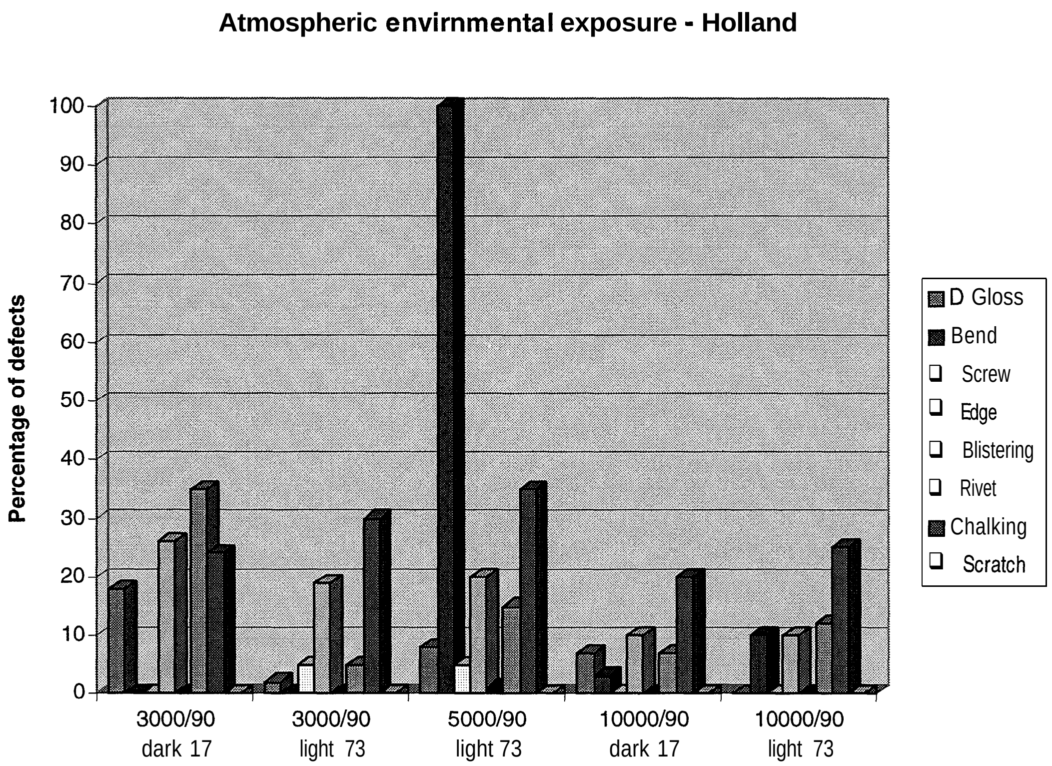

Figure 2: Results after 36 months of exposure in Holland

Results of the Dutch exposure (Figure 2) brightly show the effects of a marine environment through a high level of corrosion, on the cut edge and on the rivet, and a level of chalking higher than the one obtained after the exposure in Italy. In particular it was noticed that chalking happens with the same rate on all the samples, without correlation with the coating type.

Filling-cards of the degradation phenomena of coil coated steel sheet have been filled with the data obtained from this exposures. Anyway the application of the methodology drawn up by the research team at DISET and explained in the paper "*Methodology and experimental program to evaluate building components service life*" needed a deeper knowledge of degradation phenomena. For this reason survey were reputed necessary.

4 Results obtained from survey

Results obtained from the exposure tests in both locations were compared with the ones obtained from surveys on buildings built with the same coil coated steel sheet from 1985 to 1996. This comparison was made with the aim of obtaining an experimental validation of the mentioned filling-cards.

Relevant points were found for each building subject of survey. These points were characterized by particular exposure conditions, such as southerly exposure in places with a high sun radiation. Each point was recorded highlighting those particular aspects that may influence the natural aging of the building component, such as the distance from the sea, and reporting a brief description of the environment. The following parameters were recorded at intervals:

- color;
- gloss;
- chalking;
- dust retention,

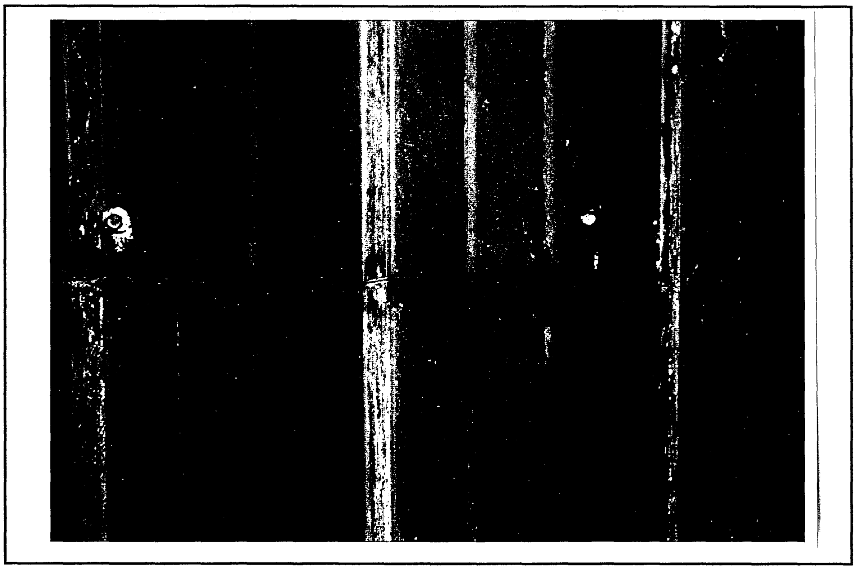

Figure 3: Particular of the external wall of a factory in Cremona (built in 1986)

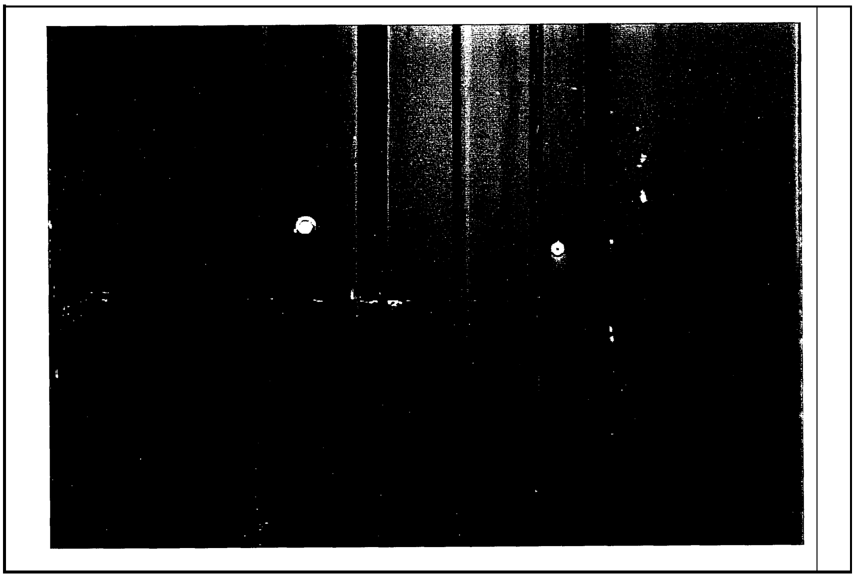

Figure 4: Particular of the external wall of a factory in Cremona (built in 1992)

Each point subject to survey is accompanied by a brief report, written on site, describing the maintenance state and highlighting, if any, external elements which may affect the maintenance state itself. Figure 3 and 4 shows two parts of a building, the first built in 1986 and the second built in 1992, subject of survey.
These surveys led to a substantial confirmation of data gained with the atmospheric environmental exposure tests, highlighting the action of sun radiation, which leads both to a discoloration even on light colored surfaces and, in association with other atmospheric agents, to chalking. The influence of air pollution and of particular kind of exposure (marine environment) is more evident in rust development. Anyway rust needs a propitious starting point such as a cutting edge or a screw hole to develop.

5 Conclusion

Data collection lead to two main conclusions:

- first of all it is necessary to proceed to a higher correlation among atmospheric environment exposure data. For this reason the Italian site is already changing its equipment in order to conform the parameters of analysis to the Dutch ones. This will allow the researchers to better understand the influence of different climate (a collection of climate and air quality data is already started);
- secondly it will be interesting to compare data obtained during surveys with the ones obtained from atmospheric environment exposure. This comparison, if related with the climate, pollution and environmental data of every site, will allow the researchers to set a quantitative relation between natural aging on site and atmospheric environmental exposure aging. This relation will lead to a quicker and more reliable evaluation of building components service life.

This experience stresses the necessity of atmospheric environmental exposure data and of surveys on existing buildings in order to obtain a better evaluation of building component service life. Only the knowledge of building components service life and of its reliability will allow everybody in the building process to make conscious choices in the direction of sustainable development. These conscious choices will turn out to be savings of natural resources which our planet is so poor of.

6 References

1. Maggi, P.N. and others (1996) *Criteri di valutazione della propensione di durata in funzione degli andamenti qualitativi di variazione delle caratterisitche funzionali delle soluzioni tecniche.*
2. UNI *8290* p.3 *Edilizia residenziale. Sistema tecnologico. Analisi degli agenti.*
3. ASTM E632 *Developing accelerated tests to aid prediction of the service life of building components and materials.*
4. BS *7453 Guide to durability of building and building elements, products and component*
5. ECCA T3 *Color difference*

Building for Environmental and Economic Sustainability (BEES)

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Abstract
The BEES (Building for Environmental and Economic Sustainability) software implements a rational, systematic technique for balancing the environmental and economic performance of building products. The technique is based on consensus standards and designed to be practical, flexible, and transparent. The Windows-based decision support software, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for a number of building products.

BEES measures the environmental performance of building products by using the environmental life-cycle assessment approach specified in the latest versions of IS0 14000 draft standards. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must therefore be analyzed. The stages include raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. Economic performance is measured using the American Society for Testing and Materials (ASTM) standard life-cycle cost method. The technique includes the costs over a given study period of initial investment, replacement, operation, maintenance and repair, and disposal. Environmental and economic performance are combined into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified according to the ASTM standard classification for building elements known as UNIFORMATII.

The BEES methodology is being refined and expanded over the next three years under sponsorship of the U.S. Environmental Protection Agency's Environmentally Preferable Purchasing (EPP) Program. The EPP program is charged with carrying out Executive Order 12873, "Federal Acquisition, Recycling, and Waste Prevention," which directs Executive agencies to reduce the environmental burdens associated with the $200 billion in products and services they purchase each year, including building products. BEES is being further developed as a tool to assist the Federal procurement community in carrying out the mandate of Executive Order 12873.
Keywords: building products, economic performance, environmental performance, green buildings, life-cycle assessment, life-cycle costing, multiattribute decision analysis, sustainable development

1 Introduction

Buildings significantly alter the environment. According to Worldwatch Institute [1], building construction consumes 40 percent of the raw stone, gravel, and sand used globally each year, and 25 percent of the virgin wood. Buildings also account for 40 percent of the energy and 16 percent of the water used annually worldwide. In the United States, about as much construction and demolition waste is produced as municipal garbage. Unhealthy indoor air is found in 30 percent of new and renovated buildings worldwide.

Negative environmental impacts arise from these activities. For example, raw materials extraction can lead to resource depletion and biological diversity losses. Building product manufacture and transport consumes energy, generating emissions linked to global warming, acid rain, and smog. Landfill problems may arise from waste generation. Poor indoor air quality may lower worker productivity and adversely affect human health.

Thus, building-related contributions to environmental problems are large, and therefore important. Selecting environmentally preferable building products is one way to improve a building's environmental performance. However, while 93 percent of U.S. consumers worry about their home's environmental impact, only 18 percent are willing to pay more to reduce the impact, according to a survey of 3,600 consumers in nine U.S. metropolitan areas [2]. To be practical, then, environmental performance must be balanced against economic performance. Even the most environmentally conscious building designer or building product manufacturer will ultimately weigh environmental benefits against economic costs. To satisfy their customers, manufacturers and designers need to develop and select building products with an attractive balance of environmental and economic performance.

In this spirit, the U.S. National Institute of Standards and Technology (NIST) Green Buildings Program began the Building for Environmental and Economic Sustainability (BEES) project in 1994. The purpose of the BEES project is to develop and implement a systematic methodology for selecting environmentally and economically balanced building products. The methodology is based on consensus standards and is designed to be practical, flexible, and transparent. The BEES model is being implemented in publicly available decision-support software, complete with actual environmental and economic performance data for a number of building products. The intended result is a cost-effective reduction in building-related contributions to environmental problems.

In 1997, the U.S. Environmental Protection Agency Environmentally Preferable Purchasing (EPP) Program also began supporting the development of BEES. The EPP program is charged with carrying out Executive Order 12873 (10/93), "Federal Acquisition, Recycling, and Waste Prevention," which directs U.S. Executive agencies to reduce the environmental burdens associated with the $200 billion in products and services they purchase each year, including building products. Over the next several years, BEES will be further developed as a tool to assist the U.S. Federal procurement community in carrying out the mandate of Executive Order 12873.

This paper describes in general terms the current formulation of the BEES model for balancing the environmental and economic performance of building products, and illustrates its application in Windows-based decision support software.

2 Methodology

The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product. Considering multiple impacts is necessary because product selection decisions based on single environmental or economic impacts, such as recylability or first cost, could obscure other impacts that might cause equal or greater damage. Similarly, considering all life-cycle stages is necessary because decisions based on a single stage, such as the use stage, could obscure other stages that might cause equal or greater damage. In other words, a multidimensional, life-cycle approach is necessary for a comprehensive, balanced analysis.

Environmental performance is quantified using the evolving, multi-disciplinary approach known as life-cycle assessment (LCA). The BEES methodology follows guidance in the IS0 14040 series of draft standards for LCA. Economic performance is separately measured using the American Society for Testing and Materials (ASTM) standard life-cycle costing (LCC) approach (ASTM E 917). These two performance measures are then synthesized into an overall performance measure using the ASTM standard for Multi-Attribute Decision Analysis (ASTM E 1765). For the entire BEES analysis, building products are defined and classified according to UNIFORMAT II, the ASTM standard classification for building elements (ASTM E 1557). All underlying data and computational algorithms are reported and documented.

2.1 Environmental performance

Environmental life-cycle assessment is a “cradle-to-grave,” systems approach for assessing environmental performance. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must therefore be analyzed, including raw materials acquisition, product manufacture, transportation, installation, operation and maintenance, and ultimately recycling and waste management.

The general LCA methodology involves four steps [3]. The *goal and scope definition* step spells out the purpose of the study and its breadth and depth. The *inventory analysis* step identifies and quantifies the environmental inputs and outputs associated with a product over its entire life-cycle. Environmental inputs include water, energy, land, and other resources; outputs include releases to air, land, and water. However, it is not these inputs and outputs, or *inventory* flows, that are of interest. More important are their consequences, or impacts on the environment. Thus, the next LCA step, *impact assessment,* characterizes these inventory flows in relation to a set of environmental impacts. For example, the impact assessment step might relate carbon dioxide emissions, a *flow*, to global warming, an *impact.* Finally, the *interpretation* step combines the environmental impacts in accordance with the goals of the LCA study. For a detailed discussion of these steps, see Lippiatt [4].

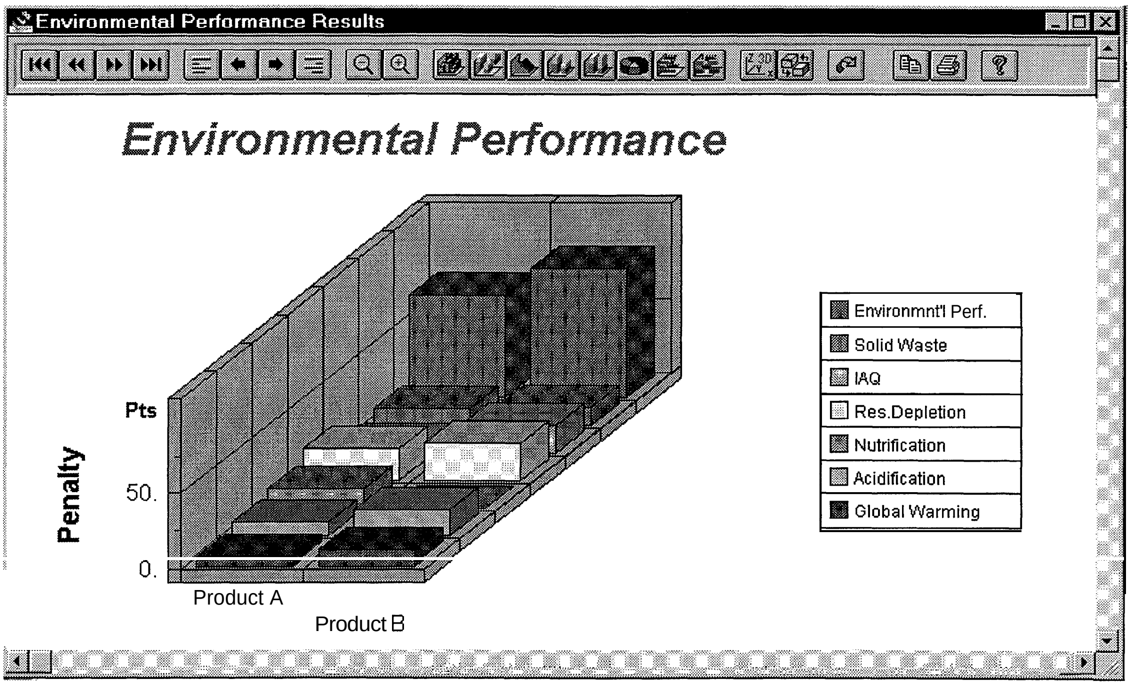

Figure 1. BEES Environmental Performance Results

The goal of the BEES LCA is to generate relative environmental scores for building product alternatives based on U.S. average data. LCA data collection is done under contract with Environmental Strategies and Solutions, Inc. (ESS) and Ecobalance, Inc., using the Ecobalance LCA database covering more than 6,000 industrial processes and gathered from actual site and literature searches from more than 15 countries. Where necessary, the data are adjusted to be representative of U.S. operations and conditions. In addition, ESS and Ecobalance gathered additional LCA data to fill data gaps for the BEES products. Assumptions made for each building product were verified through experts in the appropriate industry to assure the data are correctly incorporated in BEES.

The BEES model assesses six environmental impacts: Global Warming Potential, Acidification Potential, Nutrification Potential, Natural Resource Depletion, Indoor Air Quality, and Solid Waste. Because BEES uses U.S. average data, local impacts such as smog could not be included. Human health impacts are also excluded because the science is not yet sufficiently developed. However, if the BEES user has important knowledge about these or other potential environmental impacts, it should be brought into the interpretation of the BEES results.

Synthesizing the six impact category performance measures into a single, meaningful measure of overall environmental performance involves combining apples and oranges. BEES expresses global warming potential in carbon dioxide equivalents, acidification in hydrogen equivalents, nutrification in phosphate equivalents, natural resource depletion as a factor reflecting remaining years of use and reserve size, solid waste in volume to landfill, and indoor air quality as a dimensionless score. BEES combines these diverse measures of impact category performance into a meaningful measure of overall environmental performance using Multiattribute Decision Analysis (MADA), a technique for combining apples and oranges. The BEES system follows

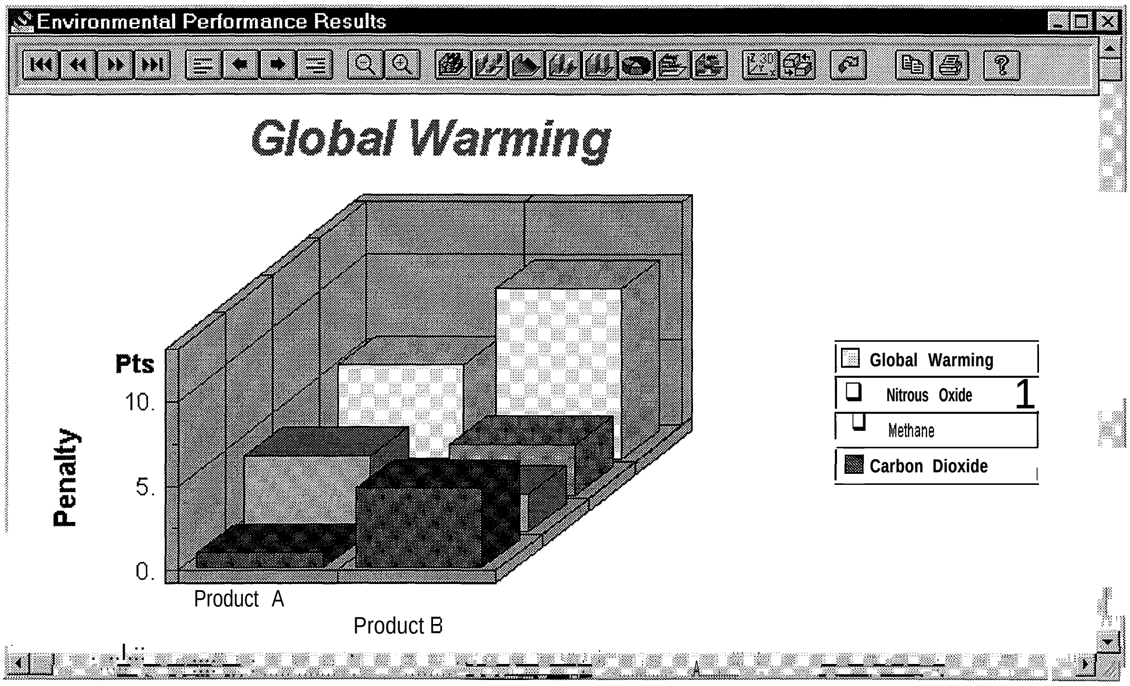

Figure 2. BEES Global Warming Performance Results

the ASTM standard for conducting MADA evaluations of building-related investments. [5]

MADA synthesizes the impact category performance measures by first placing them on a common scale, then weighting each impact category by its relative importance to environmental performance. (For a step-by-step example working through the numerical computations, see Lippiatt [4].) In the BEES software, the set of importance weights is chosen by the user. Two alternative weight sets are provided as guidance. These alternative weight sets are based on studies by the U.S. Environmental Protection Agency's Science Advisory Board and by Harvard University, and represent two different ways in which the United States, including its experts, values the environment. The BEES user may choose to use one of these weight sets unchanged, or as a starting point for developing their own set of weights.

Figure 1 illustrates the BEES graphical display of environmental performance results. The BEES environmental performance scores for Products A and B are displayed across the back row. This score is denominated in penalty points ranging from 0 to 100. As shown, Product B has worse environmental performance than Product A.

For each product, the environmental performance score is the sum of its weighted scores for the six environmental impacts, which are displayed in the remaining rows of the graph. Figure 1 illustrates the tradeoffs among environmental impacts that are often found in LCAs. Product B performs worse than Product A on global warming, acidification, resource depletion, and indoor air quality, better on nutrification, and about the same on solid waste.

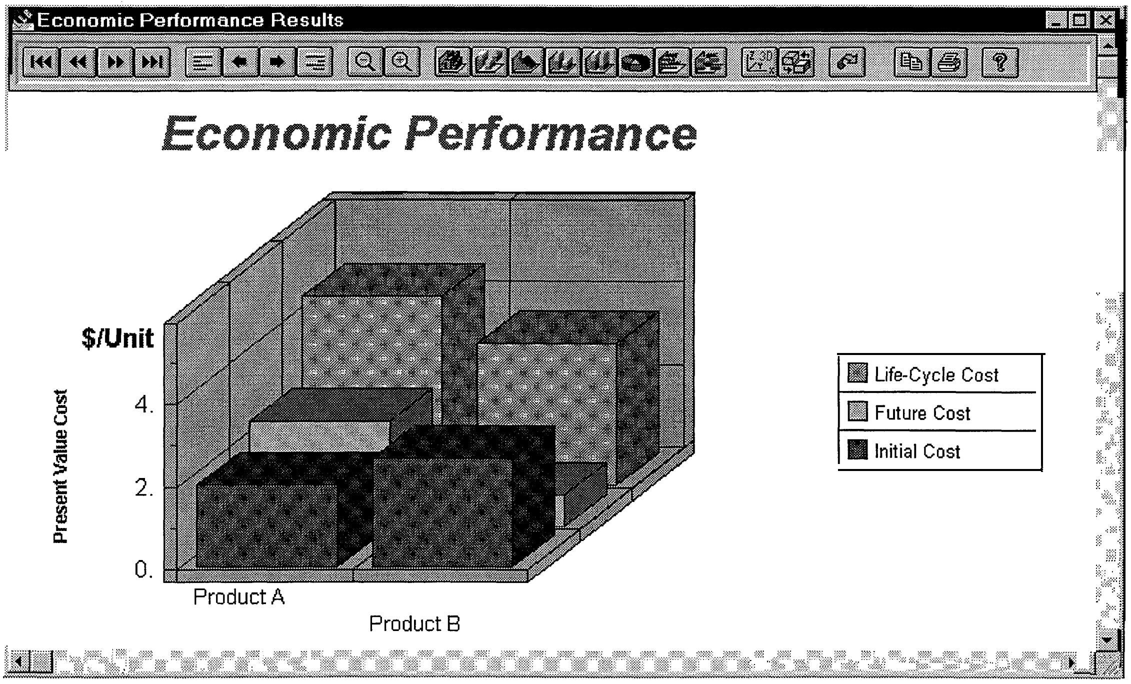

Figure 3. BEES Economic Performance Results

The BEES tool also displays detailed graphical results for each of the six environmental impacts. Figure 2 illustrates these results for the global warming impact. The global warming scores from Figure 1 for Products A and B are now displayed across the back row, with their breakdown among the contributing greenhouse gases in the remaining rows. As shown, the global warming score, which is almost twice as bad for Product B as Product A, is the sum of scores for carbon dioxide, methane, and nitrous oxide.

2.2 Economic performance

Measuring the economic performance of building products is more straightforward than measuring environmental performance. Published economic performance data are readily available, and there are well-established, standard methods for conducting economic performance evaluations. First-cost data are collected for the BEES tool from the R.S. Means publication, 1997 *Building Construction Cost Data,* and future-cost data are based on data published by Whitestone Research in *The Whitestone Building Maintenance and Repair Cost Reference 1997.* The most appropriate method for measuring the economic performance of building products is the life-cycle costing (LCC) method. BEES follows the American Society of Testing and Materials standard method for life-cycle costing of building-related investments [6].

BEES measures economic performance over a 50-year study period. The same 50-year period is used to evaluate all products, even if they have different useful lives. Evaluating products over a common time period is one of the strengths of the LCC method. It accounts for the fact that different products have different useful lives.

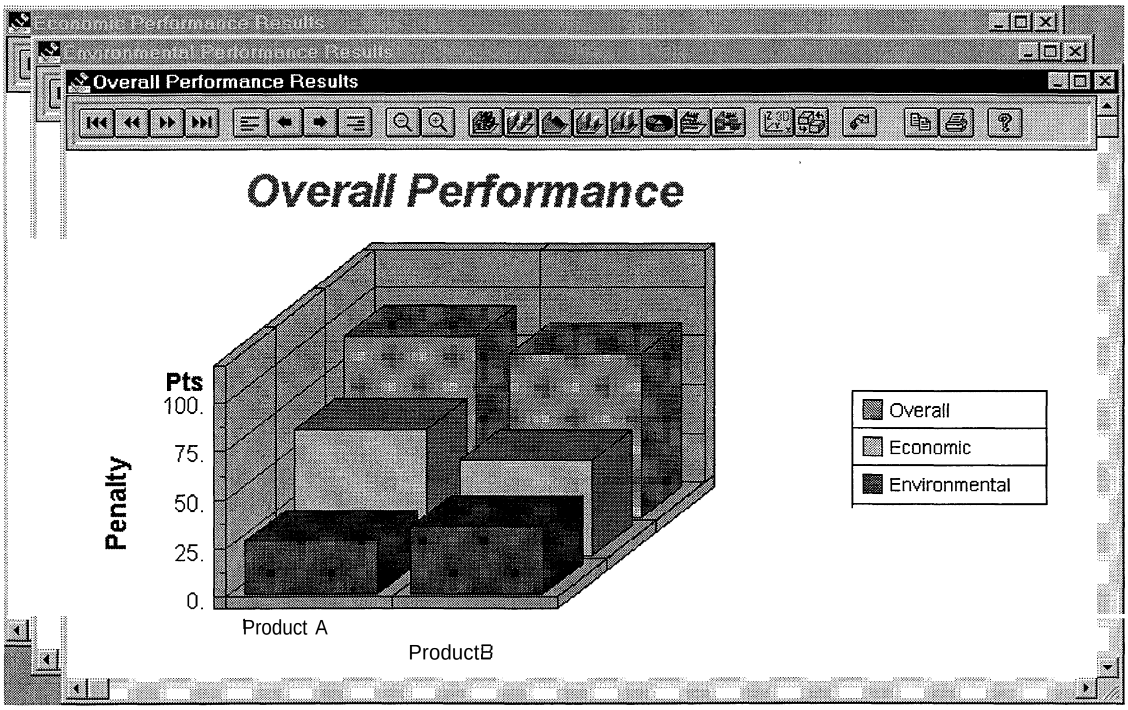

Figure 4. BEES Overall Performance Results

The LCC method sums over the study period all relevant costs associated with a product. Alternative products for the same function, say floor covering, can then be compared on the basis of their LCCs to determine which is the least-cost means of providing that function over the study period. Categories of cost typically include costs for purchase, installation, maintenance, repair, and replacement. The LCC method accounts for the time value of money by using a discount rate to convert all future costs to their equivalent present value.

Figure 3 illustrates the BEES graphical display of economic performance results for two product alternatives. The LCCs for Products A and B are displayed across the back row. As shown, Product A has a higher life-cycle cost than does Product B, even though its initial cost is lower, illustrating the importance of taking a life-cycle view.

2.3 Overall performance

BEES combines the environmental and economic performance results into a single overall performance score. To combine them, the results must first be placed on a common scale. The environmental performance score reflects *relative* environmental performance, or how much better or worse products perform with respect to one another. The life-cycle cost reflects *absolute* performance, irrespective of the set of alternatives under analysis. Before combining the two, the life-cycle cost is converted to the same, relative scale as the environmental score. Then the two performance scores are combined into a relative, overall score by assigning importance weights to environmental and economic performance. (For a step-by-step example working through the numerical computations, see Lippiatt [4].)

Figure 4 illustrates the BEES display of overall performance results. The environmental and economic performance scores from Figures 1 and 3 have been combined based on a 35 percent/65 percent environmental/economic importance weighting. The graph displays for each product its weighted environmental and economic performance scores and their sum, the overall performance score.

The BEES user specifies the importance weights used to combine environmental and economic performance scores and should test the sensitivity of the overall scores to different sets of weights.

3 Discussion and conclusions

Until now, green building decision making has been based on little structure and scientific data. There is a great deal of interesting green building information available, so in many respects we know what to *say* about green buildings. However, we have not organized and synthesized the scientific data so that we know what to *do* in a way that is both environmentally sound and cost effective.

The BEES tool satisfies this need by offering a unique blend of environmental science, decision science, and economics. It uses life-cycle concepts, is based on consensus standards, and is designed to be practical, flexible, and transparent. It is *practical* in its systematic packaging of detailed performance data in a manner that offers useful decision support. It is *flexible* in allowing tool users to customize judgments about key study parameters for which there is no consensus, such as the environmental impact category weights. Finally, it is *transparent* in providing the supporting performance data and computational algorithms.

The BEES tool will be expanded and refined over the next several years. Product technical performance will be added to the overall environmental/economic balance, and sensitivity analysis for testing the effect of changes in key study parameters will be automated. U.S. region specificity and greater flexibility in product specifications (e.g., useful lives) will also be incorporated. Finally, many more products will be added to the system so that entire building components and systems can be compared.

References

1. Roodman, D.M. and Lenssen, N. (1995) *A Building Revolution: How Ecology and Health Concerns are Transforming Construction,* Worldwatch Paper 124, Worldwatch Institute, Washington, DC.
2. Buchta, J. (Nov. 16, 1996) 1995 Home Shoppers Survey. *Minneapolis Star Tribune,* p H4.
3. International Standards Organization (1996) *Environmental Management--Life-Cycle Assessment--Principles and Framework,* Draft International Standard 14040.
4. Lippiatt, B.C. (1997) The BEES Model for Selecting Environmentally and Economically Balanced Building Products. *Environmental and Economic Balance: The 21st Century Outlook,* American Institute of Architects, Washington, D.C.
5. American Society for Testing and Materials (1995) *Standard Practice for Applying the Analytic Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems,* ASTM Designation E 1765-95, West Conshohocken, PA, USA.

6. American Society for Testing and Materials (1993) *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, ASTM Designation E 917-93, West Conshohocken, PA, USA.

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Development of the Lattice Model and its Application for the Shear Failure Mechanism

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Abstract

It is generally agreed that the truss analogy concept for shear resistance is easily applied to reinforced concrete structures. However, there exist several different truss models to analyze the shear resisting- mechanism in reinforced concrete beams. But in each model, there are still some problems to be investigated. For example, the Lattice Model, which is first proposed by Niwa et al. [10] and extended later by the authors in three dimensions [3,4], has several fundamental points to be clarified and other points to be modified. In this model the arch member is a very important concept, because after the yielding of shear reinforcement, the model can explain the increase in the shear capacity, while the simple truss model cannot, especially in the case of deep beams. The thickness of the arch element is determined by minimizing the total potential energy for the whole structure. But, any physical explanation for this minimization is not given, and once the value of the thickness of the arch element is determined in the elastic stage, this value is unchanged throughout the whole loading history. The thickness of the arch element may be changed during the loading stages, but its change is simply neglected. In this paper, we clarify this point in the first place and show the improved accuracy by performing the minimization at every loading stage.

In addition, the rational reasoning for the strain incompatibility through the width of a beam by separating the arch member and the truss member within one beam will be explained. It is found experimentally [8] that a two dimensional stress analysis is not adequate for reinforced concrete members. With these clarifications, the fundamental characteristics of the arch element mechanism for shear resistance are discussed, especially the strain values in the arch and diagonal elements in the same cross-section are not equal. The strains may not be uniform in the direction of member width. The third point to be clarified is the direction of most appropriate discretization for truss members. Finally, the application of the "Modified Lattice Model" to simulate the shear failure of reinforced concrete beams is carried out. The change of the stress states in each member inside the beam is investigated. This modified model can capture the shear behavior of concrete beams reasonably throughout the change of the shear resisting mechanism.

Key words: arch elements, modified lattice model, shear-resisting mechanism, subdiagonal element, and total potential energy.

1. Introduction

In this paper a new technique to modify the lattice model is shown. This new technique depends on the calculation of the minimum total potential energy of the structure at each step during the different loading stages. Adoption of the minimum total potential energy is studied fundamentally. The applicability of the modified model is examined by existing experimental data. Also the simulation of the shear failure mechanism for reinforced concrete beams is produced. According to the simulation and considering the objectivity of the post processing of the calculated results and the simple representation of the shear resisting mechanism, the modified lattice model can simulate the shear failure mode.

2. Outline of the modified lattice model

The chosen element discretization and structural geometry of the Modified Lattice Model is illustrated in Fig. 1. The reason behind this truss discretization will be explained in the following sections. The reinforced concrete beam has been simulated under bending and shear as simple truss components. The compressive stress in the upper part of the beam is resisted by concrete in the form of a horizontal strut with a cross-section area equal to the area of the upper rectangle in Fig. 2. The tensile stress in the lower part is taken by the bottom steel in the form of horizontal members in addition to the horizontal concrete fibers in the lower part with a cross section area equal to the lower rectangle area in Fig. 2. To resist the shear forces inside the beam, the truss model has diagonal concrete tension and compression members with the area as shown in Fig. 2, which can be fixed after the value of "t" is determined as it will be shown in section 3. In addition, there are vertical steel members, which represent the shear reinforcement in the web. Fig. 2 shows the cross section of a concrete beam modeled as a Modified Lattice Model.

In Fig. 1, the thick solid line represents the arch element which is assumed to be a flat and slender one connecting the nodes at both ends of the beam with an area as shown in Fig. 2. In this analysis, the arch element and the diagonal elements are separated and each one of them has its stress and strain distribution. The reason for this element separation is that the structural action is normally a combination of series and parallel couplings of the cracking zones and the uncracked (elastic) zones. In the Modified Lattice Model, we simulated these zones with continuous pairs of tension and compression members. Many codes [1] assume two dimensional stress fields; but if the member section is wide enough, the stress may not be uniform in the direction of member width. So, in this model we separate the arch element and the diagonal element, and each one of them has its stress and strain distribution. The

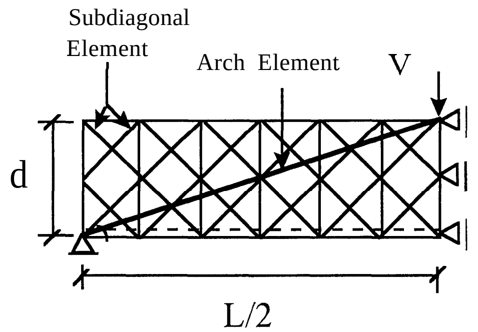


Fig. 1 Modified Lattice Model
Of Concrete Beam

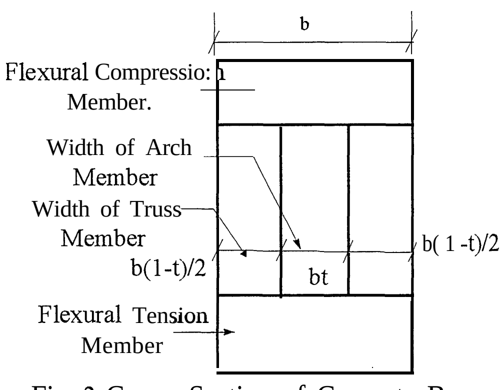


Fig. 2 Cross -Section of Concrete Beam
In Modified Lattice Model

arch element has the ability to resist a large portion of the applied load [9]. So it is very important to look for the change of the area of the arch element during the different loading stages, as it will be shown in section 3.

In the Modified Lattice Model, the diagonal tension member of concrete resists the principal tensile stress resulting from shear force. The stress-strain relation of tension member of concrete has been taken as expressed in Eq. (1) and Eq. (2) [7] and as shown in Fig. 3.

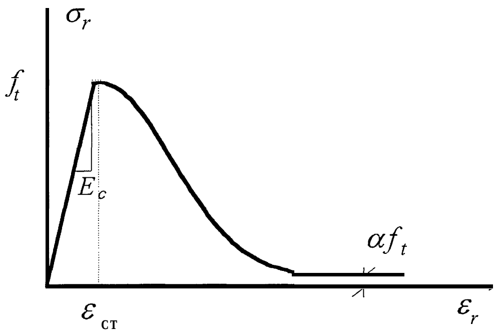


Fig. 3 Tensile Stress-Strain Curve of Concrete

For ascending branch $(\varepsilon_r < \varepsilon_{cr})$

$$\sigma_r = E_c \varepsilon_r \tag{1}$$

For descending branch $(\varepsilon_r \geq \varepsilon_{cr})$

$$\sigma_r = (1-\alpha) f_t \exp\left[-m^2\left(\frac{\varepsilon_r}{\varepsilon_{cr}} - 1\right)^2\right] + \alpha f_t \tag{2}$$

Where ε_r and σ_r are the strain and the stress of the tension element, respectively as shown in Fig. 3. Eq. (1) shows the elastic behavior before cracking. In Eq. (2), m can be varied to simulate appropriate fracture energy for plain concrete. Appropriate a value can be chosen to simulate the residual stress in the final stage of damage for simulating tension-stiffening effect in reinforced concrete [7]. In this research m=O. 5 and α=0. 0 are adopted.

The diagonal compression member of concrete and the arch member shall resist the diagonal compression caused by shear. To consider the compression-softening behavior of crushed concrete, the model proposed by Collins et al. [12] is adopted. In that model, the softening coefficient was proposed as a function of the transverse tensile strain. So, the tension and compression members are considered as a pair together as shown in Eq. (3). The stress-strain relationship for reinforcing bars is assumed to be elasto-plastic for the case of tension and compression members.

$$\sigma_c = -\eta f_c' \left(2\left(\frac{\varepsilon_c}{\varepsilon_o}\right) - \left(\frac{\varepsilon_c}{\varepsilon_o}\right)^2\right) \tag{3a}$$

Where,

$$\eta = \frac{\mathbf{10}}{\mathbf{0.8 - 0.34}\left(\frac{\varepsilon_r}{\varepsilon_o}\right)} \leq 1.0 \tag{3b}$$

And the strain at the peak stress ε_o = *-0.002.*

3. **Adoption of the minimum total potential energy**

The calculation of the total potential energy in the Modified Lattice Model has a significant effect during the calculation. It is found that there is a relation between the area of the arch element and the corresponding total potential energy of the structure. Niwa et al. [10] showed that if the ratio of the width of the arch element is assumed to be "t", the value of "t" is determined by minimizing the total potential energy for the whole structure. But in this work, it is found that this thickness is increasing gradually during the loading from the elastic stage up to the complete failure of the beam. It means that the area of the diagonal members is decreased gradually during the progress of different loading stages [5,6].

The physical explanation of the adoption of minimum total potential energy may be given using the triangular model shown in Fig. 4. The cross-section area of each of the side 1 and 2 has been divided into two different materials with two different modulus of elasticity E_1 and E_2 representing the truss element and the arch element, respectively. The ratio of the width of the arch element is assumed to be "t" from the total width of the member. The member 3 is a common material with a definite modulus of elasticity. The total potential energy of the structure is calculated from Eq. (4).

$$\pi = 1/2\int \sigma\varepsilon dv - Pu \tag{4}$$

Where u is the vertical displacement of the structure under the applied load "P". Take $\partial\pi/\partial t = 0$ to get the "t" value corresponding to the minimum total potential energy and substitute it in the energy equation. Fig. 5 shows the relation of the total potential energy and the applied load "P" for the different values of "t". From this figure we find that the point

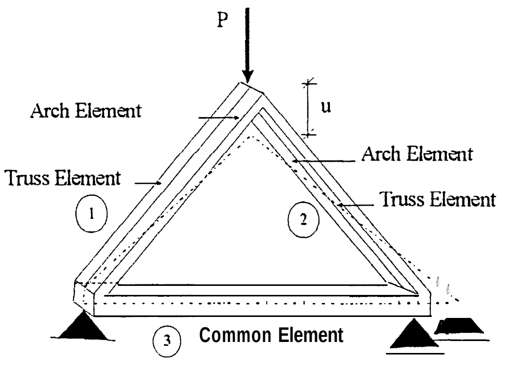


Fig .4 Triangular Model

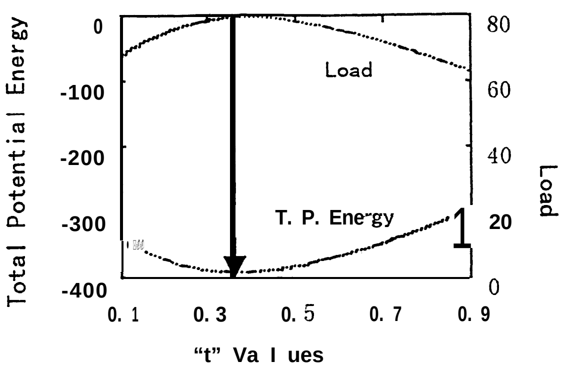
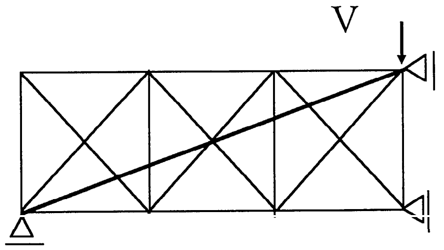


Fig. 5 Variation of T.P. Energy and Applied Load with "t" Values

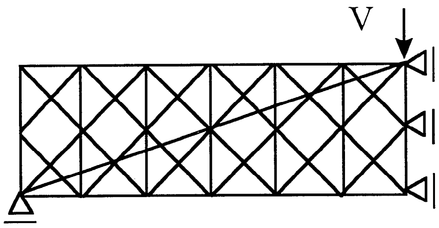
corresponding to minimum total potential energy corresponds to the maximum applied load at a definite value of "t". It means that, using this model at the minimum total potential energy we can get the stiffest beam case. Hence, in the Modified Lattice Model we calculate the total potential energy for different "t" values starting from 0.1 ~ 0.9 with a very small increment. By minimizing the total potential energy we can get the corresponding "t" value. From this "t" value we can calculate the area of the arch element and the subdiagonal elements for each step of the calculation.

4. APPROPRIATE DISCRETIZATION METHOD FOR TRUSS MEMBER

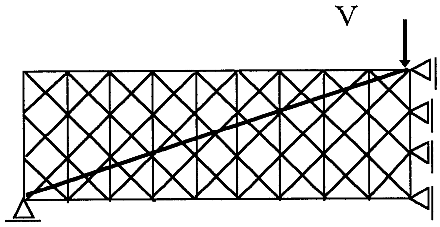
In this section a clarification of the appropriate discretization of lattice members which angle may be firstly predetermined as 45 degrees is given. To investigate the extent of the discretization, three different truss models depending on the number of diagonal pairs along the depth of the beam are investigated. The three different forms are as shown in Fig. 6. To determine the most appropriate discretization model among these three model forms, we investigated different reinforced concrete beams in order to compare the results of the Modified Lattice Model with the experimental results. The comparison of the calculated results by the Modified Lattice Model and the normal lattice model is shown in Fig. 7



(a) Model (1)



(b) Model (2)



(c) Model (3)

Fig. 6 Truss Models for Simulation (a) Model (1), (b) Model (2) And (c) Model (3)

(Ohuchi's experiment [11]). The number of subsection diagonal members is increased from model (1) to model (2) and to model (3). After cracking, the neutral axis of the beam starts to move upward during the development of the cracks. The height of the development of the cracks depends on the cross-section of the beam and the value of the steel reinforcement ratio. In case of model 2 the depth of the developed crack was similar to the experimental results during the calculation, i. e. the numerical results are close to the experimental results using this model. Therefore, it is preferable to use model (2) to implement the Modified Lattice Model. Comparing the results of the three models, we find the cracking load has been decreased starting from model (1) to model (3). In the case of model (1), the elastic energy of the failure elements is much higher than that in model (2). Also in the case of model (2) it is much higher than that in the case of model (3). The reason of that is the increasing of number of subsection diagonal members. The strain energy has been decreased with the decrease in the original length of failure elements. However, the ultimate loads using these three models are almost same because of the similarity of the fracture energy for the three different models. From these experimental data, we can say that the Modified Lattice Model can capture the displacement behavior adequately and almost reach to the same response as the original beam, especially the displacement at the peak load is similar to the experimental results. This is better than any other truss model.

The change of the thickness of the arch element is drawn in Fig. 8 (Ohuchi's experiment beam [11]). According to the Modified Lattice Model analysis, the thickness of the arch element is increasing

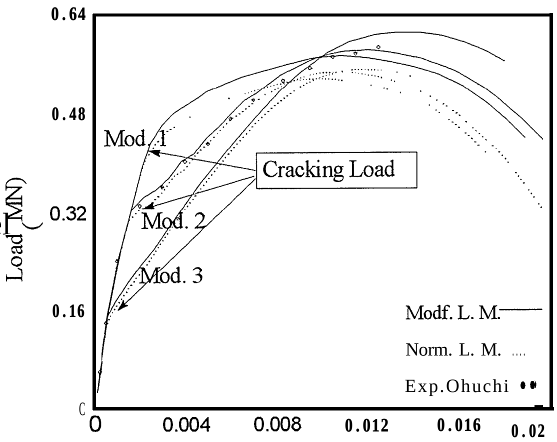


Fig. 7 Comparison of Lattice Models With Experiment data

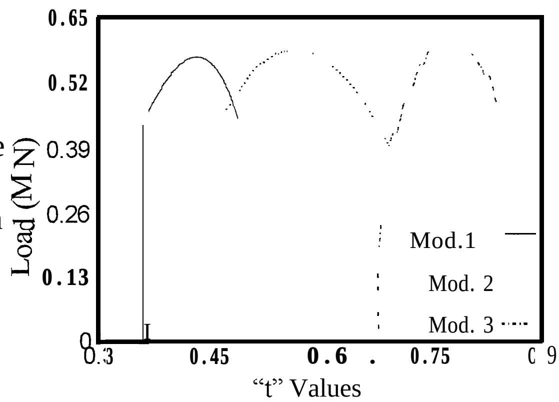


Fig. 8 Comparison of "t" Values for The Three Models

gradually from the elastic stage, in which it remains constant, up to the complete failure of the beam. After the peak point, the depth of the arch element is decreased due to the extension of the cracks. So, the thickness of the arch element has increased gradually in order to maintain the effect of the arch element up to the failure point. As have been discussed above, most appropriate truss discretization is the model (2). This suggests that the probable arch width is around 0.4b in the early loading stage which increases with the load up to 0.7b.

5. APPLICATION OF THE MODIFIED LATTICE MODEL FOR SHEAR FAILURE SIMULATION

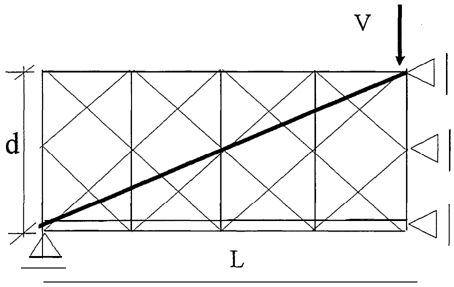
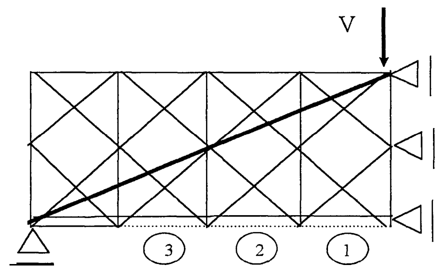
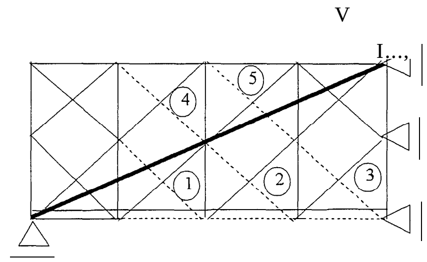


Fig. 9 Illustrative Beam Example

The Modified Lattice Model is easily applicable to simulate the shear failure mechanism for the reinforced concrete beams. Clark's experiment [2] was chosen as an example for the simulation. Fig. 9 shows the Modified Lattice Model for the reinforced concrete beam [2]. The stresses in diagonal members of concrete and stirrups and the stress of arch member are examined. From the output results of the simulation, using the Modified Lattice Model, it is found that at the primary cracking stage, the concrete elements in the bottom cord start to crack first as shown in Fig. 10 (a). Then the initiation of the diagonal cracking happens as shown in Fig. 10 (b). The initiation of the yielding of stirrups starts to take place. Although the stirrups start yielding and the diagonal tension elements have cracked, but the beam still continue to be loaded up to the complete failure. That is because of the existence of some stirrups without yielding and also the arch element, which continues up to the complete failure of the structure. At the final stage, all the stirrups yielded. At that time the arch element crushed immediately. From this simulation for the failure of that beam we can consider it as a shear failure.



(a) Cracks in Bottom Members



(b) Cracks in Diagonal Members

Fig. 10 The Propagation of Cracks

6. ILLUSTRATIVE EXAMPLE

To investigate the change of the stress states in each member inside the reinforced concrete beam using the suggested Modified Lattice Model Clarck's experiment [2] in Fig. 9 is studied as an example. Studying only the average of the solid members located in the center of the shear span as in Fig. 11. The change of the average stress in diagonal members of concrete and stirrups and the stress of arch member are examined. The stresses are calculated and shown

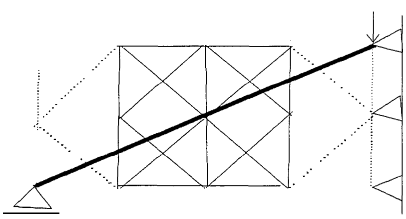
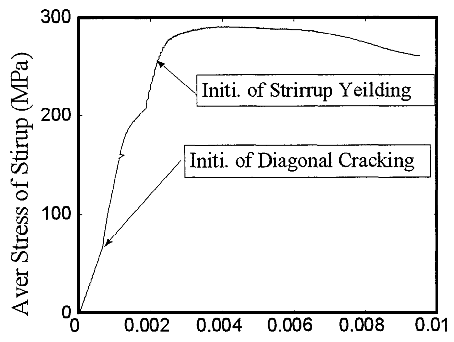
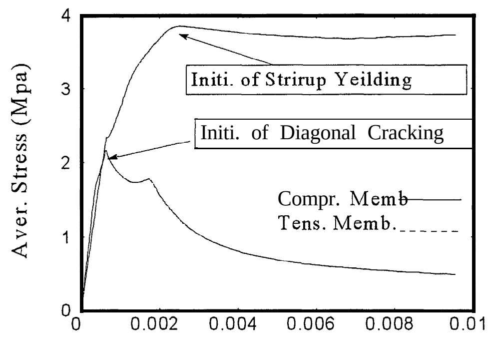


Fig. **11** Average Members in the Centre of Shear span

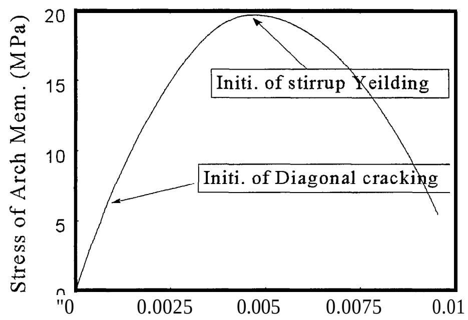


(a) Average Stress of Stirrups



(b) Average Stress of Diagonal tension and Compression Members

in Fig. 12 with the increase in the displacement of the loading point. From Fig. 12, it is clear **that the** average tensile stress of diagonal tension members of concrete is decreasing rapidly after the initiation of diagonal cracking. On the other hand, the average compressive stress of diagonal compression members of concrete and average tensile stress of stirrups are increasing significantly as shown in Fig. 12(a), and (b). The average stress of diagonal compression members has the tendency to remain almost constant after exhibiting a certain amount of increase in the average stress. The average stress in stirrups is slightly increasing with the increase in the displacement after the initiation of yielding. However, the compressive stress in arch member exhibits a significant increase after the initiation of stirrup yielding, however, due to the softening in compression, the arch member reaches to the ultimate state as in Fig. 12(c). Hence, the predicted shear failure mode for this beam is compression failure of arch member after the initiation of stirrup yielding. This is quite similar to the experimental results.



(c) Stress of Arch Member

Fig. (12) Change of Average Stress in each Member

7. CONCLUSIONS

In the proposed Modified Lattice Model, a reinforced concrete beam subjected to shear force is converted into a simple truss and arch members by the consideration of the minimum total potential energy for the structure at each step of loading. A nonlinear incremental analysis is performed. The conclusions obtained from this research are as follows:

1. By minimizing the total potential energy of the reinforced concrete beam, we get only one value for the thickness of the arch element, which corresponds to the stiffest case of the structure which is quite similar to the original response of the experimental analysis.
2. The modified Lattice Model has the tendency to estimate the stiffness of the beam closer to the experimental results. Furthermore, the predicted displacement at the peak is almost similar to the experimental results.

3. The thickness of the arch member, which plays a very important role in the Modified Lattice Model, is increasing gradually with the increase in displacement of the loading point after the initiation of diagonal cracks up to the complete failure of the beam.
4. Model (2) is the appropriate discretization to implement the Modified Lattice Model analysis.
5. Using the different forms of the Modified Lattice Model, the ultimate load is almost kept constant but the cracking load is decreasing depending on the strain energy of the cracked element.
6. Although the Modified Model is a more simplified method than the normal finite element method, it can capture the shear behavior of concrete beams throughout the change of the shear resisting mechanism.

REFERENCES

1. Comite Euro-International du Beton. (1978) *CEB-FIP model code,* Lausanne, Switzerland.
2. Clark, A.P., (1989) "Diagonal Tension in Reinforced Concrete Beams", *ACI Journal,* pp.507~515.
3. EL-Behairy, F.M. Niwa, J. and Tanabe, T. (1996) "Analytical Study on Pure Torsion Behavior of Concrete Columns Using 3D-Lattice Model." *Proc. JCI,* Vol.18, No.2, pp. *263-268.*
4. El-Behairy, F.M., Niwa, J. and Tanabe, T. (1996) "Simulation of the R.C. Column Behavior in 3D- Stress State Under Pure Torsion Using 3D-Lattice Model." *Proc. of JCI Transaction,* Vol. 18 pp. 303-308.
5. EL-Behairy, F.M. and Tanabe, T. (1997) "A new Technique for Reinforced Concrete Beam Analysis Using the Modified Lattice Model." *Proc. JCI,* Vol. 19, No.2, pp. 477-*482.*
6. El-Behairy, F.M., and Tanabe, T., "Appropriate Discretization Method for Reinforced Concrete Analysis using the Modified Lattice Model ", *Proc. of JCI Transaction,* Submitted by Augst, 1997, to appear.
7. Gupta, S. (1997) "The Development of Unified Concrete Plasticity Model for Three Dimensioned Analysis of Reinforced Concrete Members", *Doctoral Thesis,* Nagoya University, Japan.
8. Ichinose, T., Hanya K. (1995) "Three Dimensional Shear Failure of RC Columns", *Concrete Under Severe Conditions Environment and Loading,* Vo1.2, Edited by K. Sakai, pp. 1737-1747.
9. Minami K. (1982) "Limit Analysis of Shear in Reinforced Concrete Members", Proc. of *JCI Colloquium* on Shear Analysis of RC Structures.
10 Niwa, J., Choi, I. C., and Tanabe, T. (1994) "Analytical Study for Shear Resisting Mechanism Using Lattice Model", *JCI International Workshop* on Shear in Concrete Structures, pp. 130~145, 20.
11 Ohuchi, H. et al. (1991) "Shear Experiment on Concrete Beams Using High Strength Concrete and High Strength Bars", *Proc.* of *JSCE* 46 the Annual Conference, Vol. 341, pp.698~699.
12 Vecchio, F. J., Collins, M.P. (1985) "The Modified Compression Field Theory for Reinforced Concrete Elements Subjected to Shear", *ACI Journal,* pp.2 19-23 1.

Durability of elastomeric building sealants — results from a five year programme

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Abstract
An extensive and comprehensive multi-year durability study was undertaken in which a series of high-performance sealant products were artificially and naturally aged in an effort to determine test methods and test regimes most likely to simulate in-service conditions. Sixteen elastomeric products were evaluated of which fourteen were sealants based on either polysulphide, polyurethane or silicone compounds. The remaining products, an ethylene-propylene-diene-monomer and a polychloroprene, were used as a basis of comparison to the ageing effects on rubbery compounds subjected to both artificial and natural ageing. Both free-film and model joint compounds were tested. Artificial ageing was conducted using different weathering apparatus and consisted of various combinations of exposure to fluorescent or Xenon lamp Ultra violet radiation, simultaneous heat ageing at temperatures ranging from 60 to 140°C and, water condensation or spray. Natural ageing took place on a site located near the test laboratories and characterised by its temperate climate and industrial setting. The change in materials properties was characterised through mechanical tests (tensile strength and elongation at break), thermo-analytical methods and chemical spectroscopy including attenuated total reflectance and photo-acoustic Fourier transform infrared spectroscopy. Results from specimens aged artificially are compared with those aged from 5 years open air weathering in Leipzig. As well, results on model joints are compared with those obtained from testing free-films. These preliminary results strongly suggest that the research should continue such that a comprehensive assessment of different ageing regimes and their effects on various sealant products can be ascertained. This work would then provide a fundamental basis for developing useful and predictive assessment tests for sealant products currently in use.
Keywords: accelerated ageing, chemical spectroscopy, correlation, cyclic movement, elastomeric sealants, free films, joint models, natural weathering, thermo-analytical, time compression factor.

1 Introduction

There exist a number of problems associated with developing useful tests to assess the long-term performance of sealants. To adequately assess their long-term performance, a great deal of testing and time is required in relation to the actual time in-service. Typically, the long-term performance of sealant products is assessed on the basis of practical experience derived from field studies [8]. Field studies undertaken to the evaluate products tested in present study will be reported in a subsequent conference to be held in Berlin this June [2]. The present work focuses on the results of laboratory studies using artificial and natural ageing conditions as a basis for developing standard test methods. To yield useful and reproducible results, standard test methods require simplified test conditions, reduced testing periods and test conditions in which the number of factors causing ageing are minimised. An understanding of factors that influence the long-term testing of building sealants is critical to the development of suitable test methods

2 Experimental

2.1 Materials

The elastomeric sealants evaluated in this study are given in Table 1 below. The products are representative of the most widely used high-performance products, namely, silicone, polysulphide and polyurethane based sealants. In order to offer some comparison to the properties of other rubbery compounds used in building construction, the sealant products were compared to both polychloroprene an EPDM rubber compounds. The colour and curing system are provided for each of the 16 products tested. Two types of joint specimen were prepared: free-film specimens having dimensions of 900 mm x 80 mm x 2-3 mm, and model joint specimens conforming to ISO 8339 [10].

Table 1 — Material types, curing systems and colours

No.	Material type	Curing system	Colour
A5		1 part neutral cure, Oxime based	Grey
A6		1 part basic cure, Amine-Oxime based	Grey
A7		1 part neutral cure, Oxime based	White
A8	Silicone rubber	1 part neutral cure, Oxime based	White
A17		1 part neutral cure, Alkoxy-Titanium based	White
A18		1 part neutral cure, Benzamido-Titanium based	Grey
A19		1 part neutral cure, Benzamide based	White
A21		1 part acid cure, Acetate based	White
B9	Polysulphide	2-part Manganese dioxide cure	Grey
B10	rubber	2-part Manganese dioxide cure	Grey
B12		2-part Manganese dioxide cure	Black
B22		2-part Lead dioxide cure	Grey
B28		Prefabricated	Grey
C23	Polyurethane	1-part	Grey
D24	Polychloroprene	vulcanised	Black
E25	EPDM rubber	vulcanised	Black

2.2 Test series

Six different series of tests samples were prepared such that the effects of weathering using different accelerated ageing techniques could be compared to that of natural ageing (Table 2). The majority of tests were conducted on free films; however, results of tests were compared to those obtained on model joints.

Table 2 — Description of test series and related apparatus for conducting ageing studies

Test series No.	Description	Apparatus
1	Fluorescent UV radiation and heat ageing at + 50°C	UVCON (Atlas); UVA 340 lamps
2	Xenon arc UV radiation and heat ageing at + 50°C	Suntest CPS (Heraeus); NXE 1500 lamps
3	Thermal ageing at different temperatures up to + 90°C	Heat ageing ovens
4	Test Series No. 1 combined with extension and compression of model joints	UVCON (Atlas); UVA 340 lamps
5	Natural weathering at an outdoor site in Leipzig	Nil
6	Control specimens stored in laboratory conditions (DIN 53386-A [4])	Nil

Details regarding the test conditions and specimen exposure regimes are given below for each of the test series.

2.2.1 Ageing using fluorescent UV radiation and heat

Free-film specimens were evaluated for changes in mechanical properties and variations in chemical structure after every 1000 hours exposure for up to a total 6000 hours exposure in the accelerated weathering apparatus given in Table 1 above. Four different cycles were used to assess variations in the ageing regimes, including:

i.) 8hrs UV at + 60°C; 4 hrs heat ageing at + 50°C
ii.) 8hrs UV at + 70°C; 4 hrs heat ageing at + 50°C
iii.) 8hrs UV at + 80°C; 4 hrs heat ageing at + 50°C
iv.) 8hrs UV at + 90°C; 4 hrs heat ageing at + 50°C

2.2.2 Ageing using Xenon-arc radiation, heat and water spray

Specimens were likewise subjected to exposure intervals of 1000 hours for up to 6000 hours of total exposure. Mechanical properties were determined and chemical analysis was performed on free-film specimens after each ageing interval. Over a 21-day period, the ageing cycle consisted of 3 consecutive cycles of:

- 3 days at + 80°C; 1 day of H_2O; 2 days at + 80°C; 1 day of H_2O.

2.2.3 Thermal ageing
Thermal ageing was conducted on free-film specimens over a 6000-hour period with ageing intervals of 1000 hours respectively. Two sets of heat ageing tests were carried out: the first subjected specimens to temperatures ranging from + 60°C to + 90°C over extended periods of time; the second set was used to subject specimens to heat ageing at higher temperatures (i.e., + 100°C, +110°C, +120°C, +140°C) but for shorter intervals (i.e., up to 3500 hours total exposure with intervals of 500 hours)

2.2.4 Artificial ageing combined with extension and compression
Model joints prepared in accordance with ISO 8339 [10] were subjected to artificial ageing conditions for periods of up to 6000 hours. Strains were applied (± 7.5% and ± 12.5% of joint width) to these joints (ISO 9047 [11]) prior to the start of each ageing interval of 1000 hours. The ageing regime consisted of:

- 8hrs UV at + 60°C; 4 hrs heat ageing at + 50°C
- 8hrs UV at + 70°C; 4 hrs heat ageing at + 50°C
- 8hrs UV at + 80°C; 4 hrs heat ageing at + 50°C

During the ageing process, strains were altered from the extended state to the compressed state every two weeks.

2.2.5 Natural ageing
Free-film and model joint compounds (ISO 8339 [10]) were exposed to natural ageing at an outdoor test site located in Leipzig, that has a temperature climate and local conditions suggest and industrial setting. This ageing regime started in January 1993. The model joint compounds were also subjected to two strain levels: ± 7.5% and ± 12.5% of joint width. Changes in extension and compression were made at the same intervals as was previously given above in 2.2.4.

2.3 Test methods

2.3.1 Mechanical tests
Prior to testing, all samples were stored in standard conditions of 23°C and 50% RH in accordance with DIN 50014 [3]. Following this, three strips were cut from specimens of 45-mm length and tested in tension according to both DIN 53504 [5] and ISO 33 [9] respectively. Both tensile strength and elongation at break were recorded for each of the specimens. Tensile tests on thin strips potentially eliminate the effect of substrate since for the majority of sealant products this does not have a negative effect [1].

Tensile tests on model joint compounds was carried out using ISO 8339 [10] and provided information regarding the tensile strength and elongation at break and the tensile modulus.

2.3.2 Physical-chemical tests
The glass transition temperature of weathered samples was determined using a dynamic differential scanning calorimeter (DSC), model DSC 200 (Netzsch Geraeteban). Chemical changes at the surface of the weathered samples were examined using attenuated total reflectance (ATR) Fourier transform infrared (FTIR) spectroscopy (IMPACT 400, Nicolet). As well, photo acoustic (PAS) FTIR

spectroscopy was used to examine the surface of samples that had a severely degraded surface since this technique readily lends itself to chemical analysis in instances where surfaces are sufficiently deteriorated as to render the ATR method useless. For the PAS technique, a MTEC model 300 photoacoustic cell was used to collect the requisite data.

3 Results

The results from these ageing tests indicated that almost all of the materials survived artificial ageing at temperatures between + 60 and + 120°C. Specific results of tensile testing of artificially and naturally aged free-film specimens is provided in the first two parts of this section and results regarding model joints are discussed in subsequent parts. No detailed description of the results obtained from the chemical analysis is provided in this paper although a summary statement is given in the final part of this section.

3.1 Tensile tests on free-films

3.1.1 Artificial ageing
Based on the results obtained from these tests, the 16 products evaluated in this study can be classified in essentially three (3) different materials "types", corresponding to their response to artificial ageing and related physical characteristics. These are:

i.) Type 1 materials have elongation at break (ε_r) that change as a function of temperature in accordance with the Arrhenius equation whilst not having any evident nor significant effect on the strength at break. An example of a Type 1 material is provided in Figures 1-4 that depict changes in properties of product B28. Type 1 materials include products: B9, B10, B22, B28, C23, D24 and E25

ii.) Materials characteristic of Type 2 suggest that the tensile strength at break (σ_r) follow the Arrhenius relationship whereas the strain at break is not coupled to changes in temperature. An example of this relationship is given in Figures 5-8 showing changes in σ_r over different exposure times for product A17. Materials in this category include products A17 and B12.

iii.) Type 3 materials are characterised by little or no aged-induced changes in a given ageing regime. Essentially, the materials are only slightly or completely insensitive to the effects of heat, UV and water in the exposure regimes and over the time intervals over which they were tested. This is evident in instances where the ageing effects act alone or indeed where the ageing period was prolonged from 6000 hours to 12000 hours. Representative of this material type is product A19, whose results are provided in Figures 9-12 respectively. Materials of this type include products: A5, A6, A7, A8, A18, A19 and A21.

3.1.2 Comparison of artificial ageing and natural weathering
At this stage, data for specimens exposed to natural weathering over a 5 year period is available for the 16 products evaluated. An important result from these tests

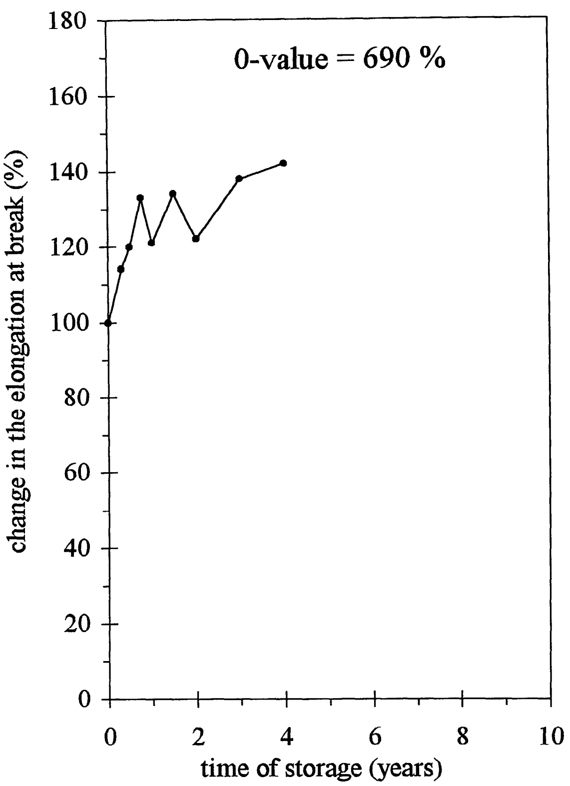

Fig. 1: Material B 28 - natural weathering

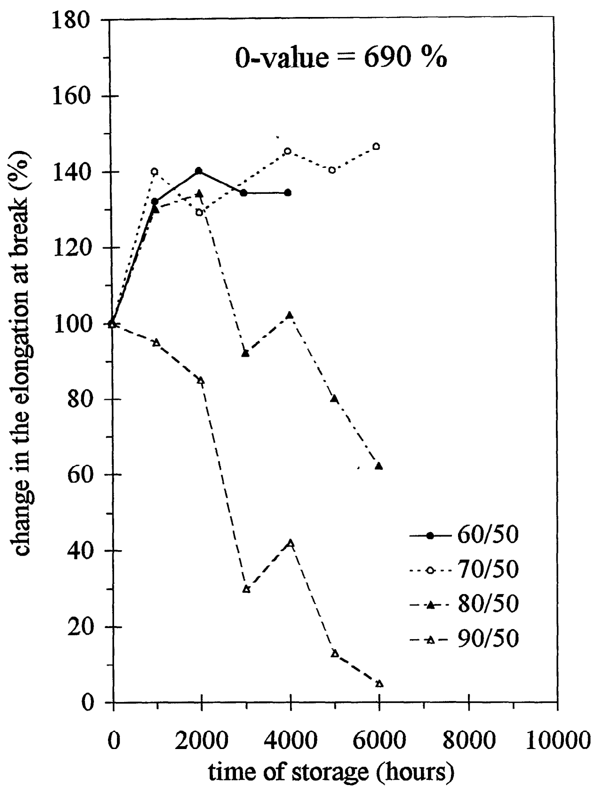

Fig. 2: Material B 28 - accelerated ageing UVCON

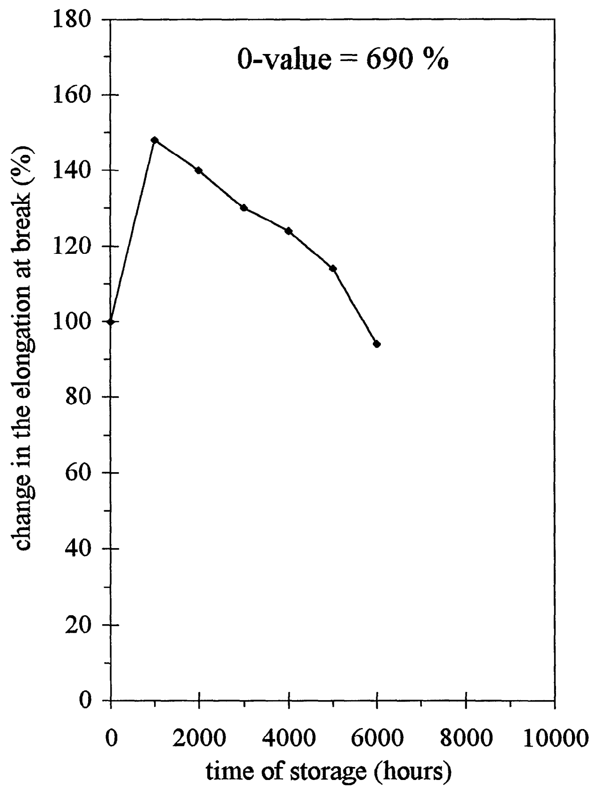

Fig. 3: Material B 28 - accelerated ageing SUNTEST

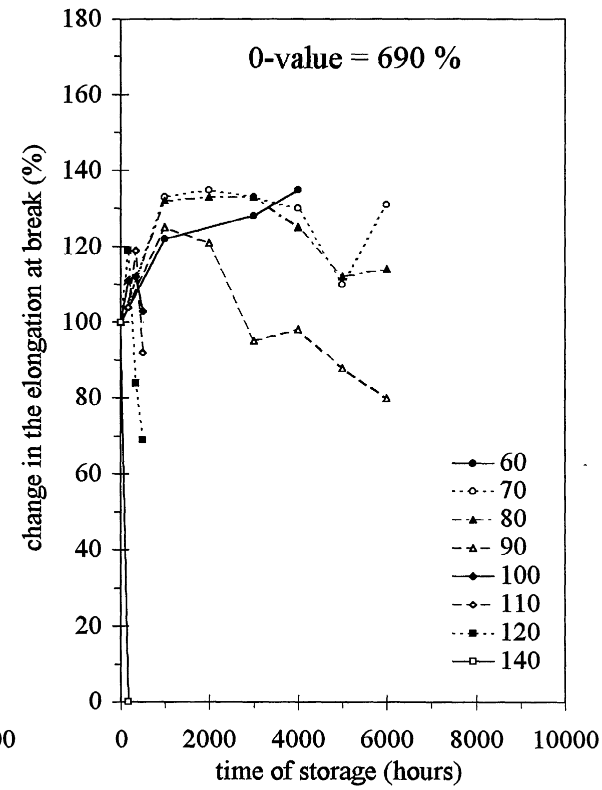

Fig. 4: Material B 28 - accelerated ageing OVEN

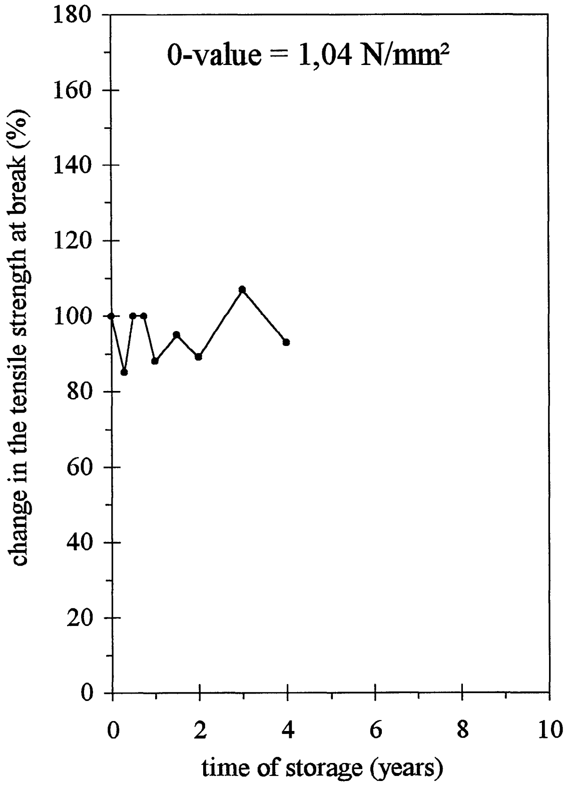

Fig. 5: Material A 17 - natural weathering

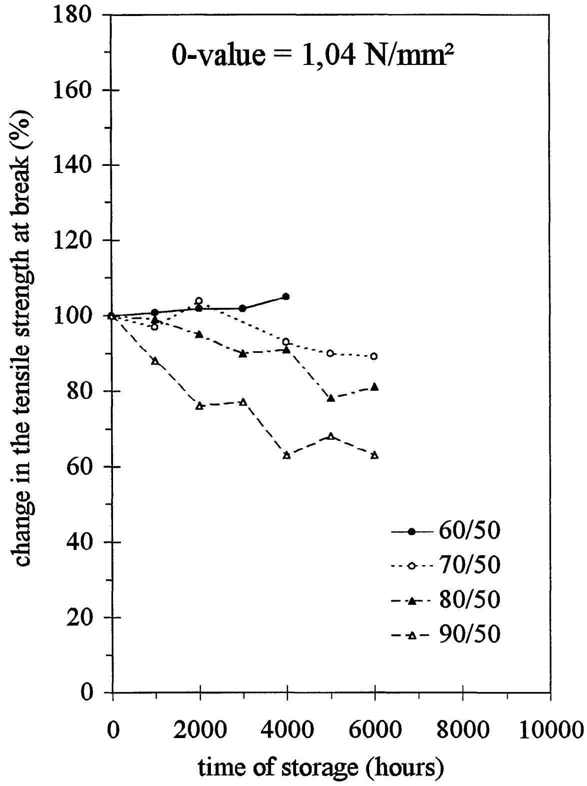

Fig. 6: Material A 17 - accelerated ageing UVCON

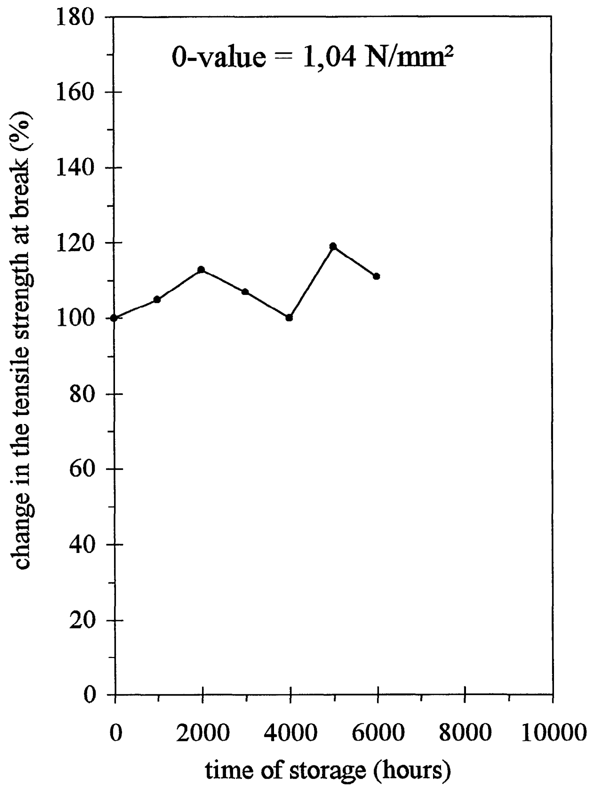

Fig. 7: Material A 17 - accelerated ageing SUNTEST

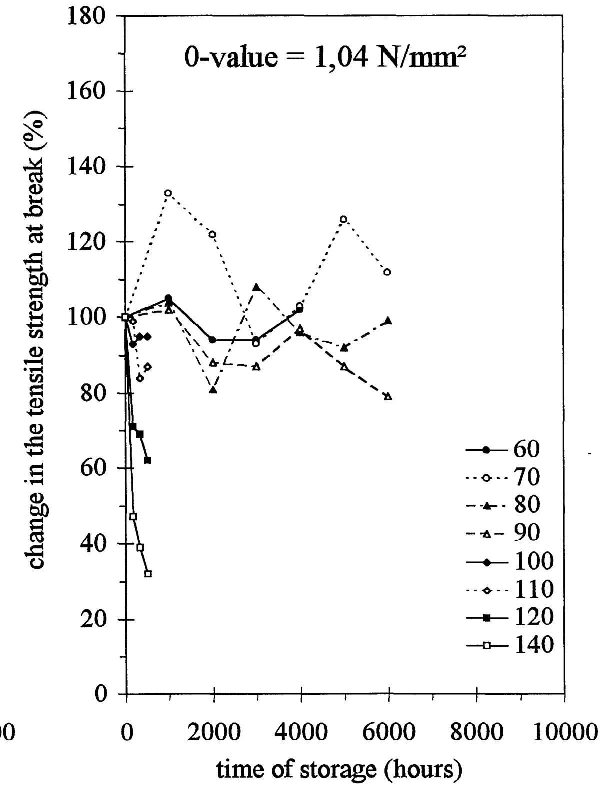

Fig. 8: Material A 17 - accelerated ageing OVEN

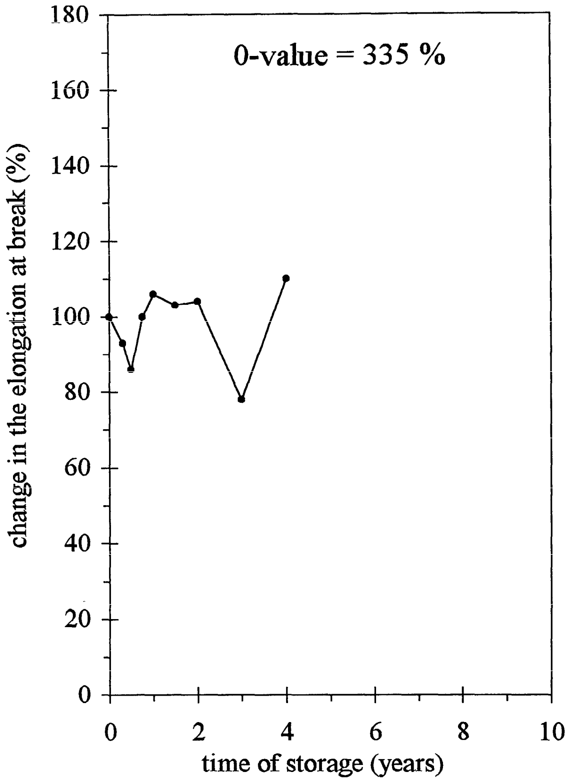

Fig. 9: Material A 19 - natural weathering

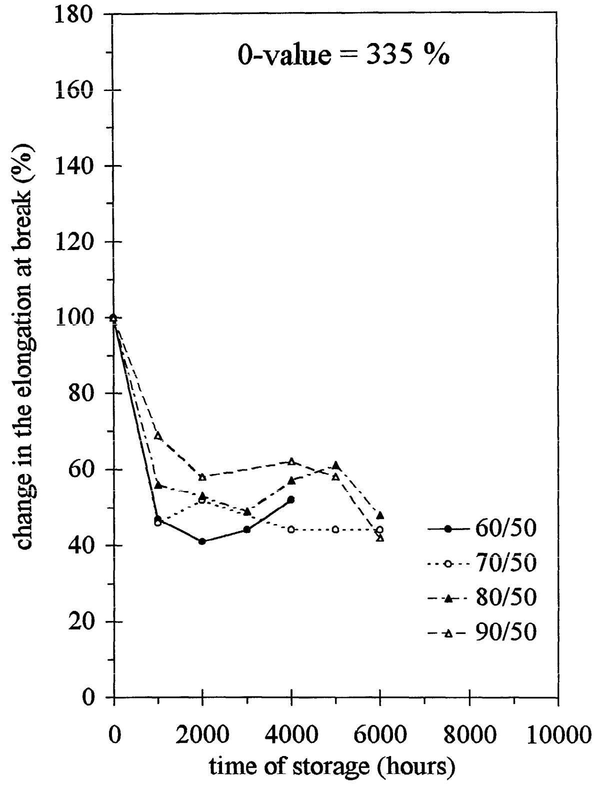

Fig. 10 Material A 19 - accelerated ageing UVCON

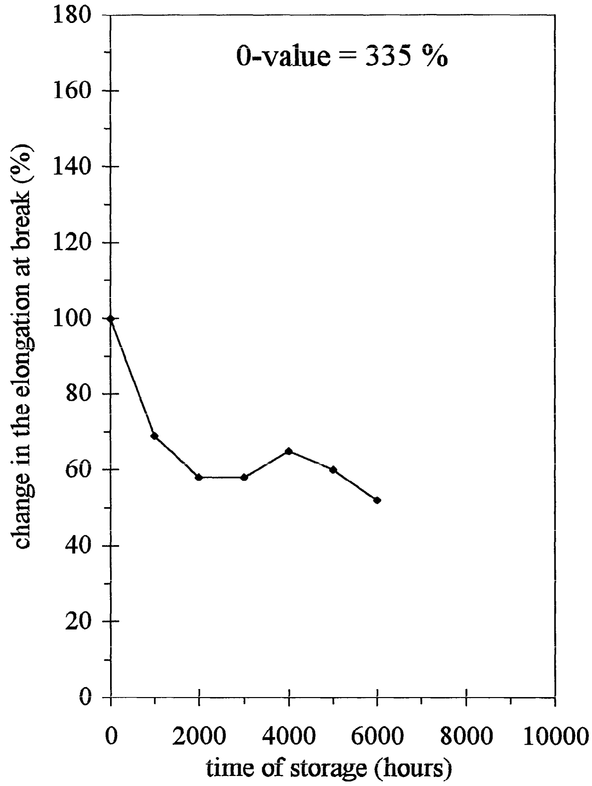

Fig. 11: Material A 19 - accelerated ageing SUNTEST

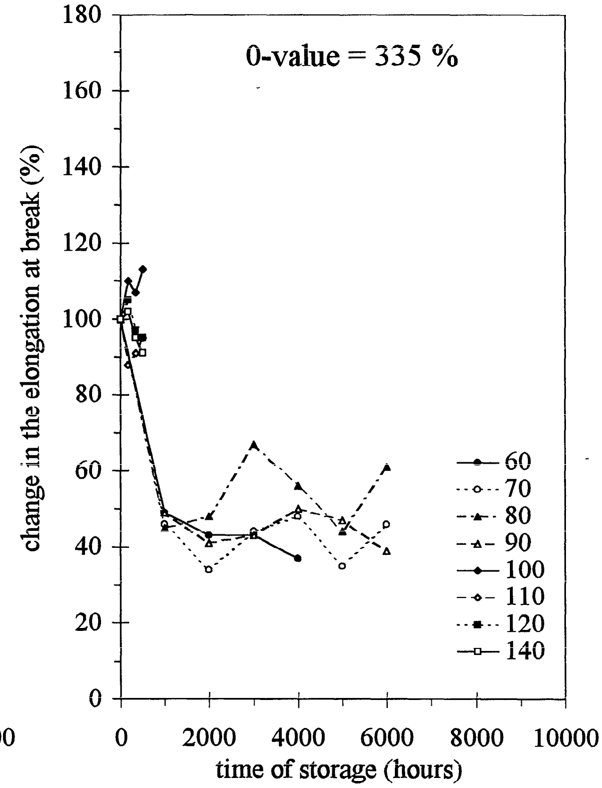

Fig. 12: Material A 19 - accelerated ageing OVEN

showed that post-curing can take place over one year in certain materials and actual ageing appears to only take place thereafter.

For civil engineering applications in-service temperature for sealants are not expected to exceed 70°C and typically, higher test temperature are likewise not used. Assuming results between natural ageing over 4 years and artificial ageing over 36 weeks (6000 hours) correlate reasonable well, one can then postulate that there exists a time-compression factor of 1:6 (32 weeks: 4 x 52 weeks). The current results indicate that virtually all sealants can be tested to temperatures of at least 90°C without adverse effects. Assuming that this can be extended to higher temperatures as wee, time-compression factors for different test temperatures can be calculated from the Arrhenius equation as provided in Table 3 below.

Table 3 — Estimated time-compression factors at given temperatures

Test temperature °C	Time-compression factor
70	1:6
80	1:12
90	1:24
100	1:48
110	1:96
120	1:192

It is to be noted that each 10°C increase in test temperature doubles the time-compression factor. The implications regarding this proposal suggest that considerable savings in time and costs can accrue provided the applicability of test temperatures in excess of 70°C can be substantiated by additional work. Based on these promising initial results, the current test series is being extended. As well, the degree of correlation declines only slightly with increases in test temperature within the range of temperatures examined in this study.

3.2 Tests on model joints in comparison to free-films

Model joints were tested on 10 of the 16 products evaluated in this study. Changes in tensile strength and elongation at break for specimens exposed to 4 years natural weathering were similar to results obtained from free-films with the exception of material A5. In this case, results obtained for the elongation at break from the free-film specimen did not correspond to that of the model joint compound; it is not possible at this time to offer an explanation for this occurrence. In the case of materials A5, A6, A7, A8 and C23, it was possible to obtain values for both the tensile strength and elongation at break whereas for the remaining materials, adhesion was lost prior to being obtaining useful results.

Model joints subjected to artificial ageing series No. 1 provided similar results to those aged in natural conditions based on results of tensile tests on products A5 and A6. It must also be noted that post-curing occurs more slowly in model joints as compared to free-films and as well, the effect of UV radiation is less pronounced in model joint specimens. Ultra violet radiation essentially produces only surface effects. Results for values of modulus at 50 and 100% extension did not provide as clear an indication of changes in performance as was evident for either the tensile strength or elongation at break and hence, these values have not been reported here.

3.3 Comparison of Ageing with movement cycles

The results of this section as based on three products namely, A5, A6 and C23. Products A5 and A6 were chosen as being representative because they were found to be particularly resistant to artificial ageing, as was seen in previous test results. As well, all these products preferentially had excellent adhesion to the concrete substrate and consequently failed in cohesion. Product C23 is the weakest material despite its' excellent adhesion to concrete.

The remaining tests have not yet been completed however the status of the various test series is provided below in Table 4.

Table 4 — Description and status of Natural and Artificial weathering test series for elastomeric sealant products

Series description	Status
NW[1] with and without extension of +25%[†]	5 years natural exposure
NW with 1 extension/compression cycle /yr.: 6 months at +12% (winter); 6 months at -12% (summer)	1 year natural exposure
NW with 6 extension/compression cycles /yr.: 1 month at +12%; 1 month at –12%	1 year natural exposure
AW[2] using UV CON at 80°C /50°C and extension/compression cycling, alternating every 1000 hrs between +12.5% (at –20 °C) and –12.5% (at 80°C)	Complete after 6000 hours exposure
AW using UV CON at 70°C /50°C with extension/compression cycling, alternating every 2 wk. between +12.5% (at –20 °C) and –12.5% (at 70°C)	Complete after 6000 hours exposure
AW using UV CON at 60°C /50°C with extension/compression cycling, alternating every 2 wk. between +12.5% (at –20 °C) and –12.5% (at 60°C)	4000 (of 6000) hours completed

1. NW – Natural weathering
2. AW – Artificial weathering

† + Indicates extension and - compression

Preliminary results from this test series suggest that continuos extension alone has only a very slight effect whilst artificial ageing with simultaneous extension-compression cycling has a significant negative effect. Work in the area of artificial ageing should continue with emphasis on separate extension-compression cycles having lesser effects than those previously undertaken. It is likely that these would more closely resemble in-service conditions.

3.4 Physical-chemical test methods

Based on results obtained to date, the use of DSC appears to be the most suitable method for investigating changes in glass transition temperature (T_g) for elastomeric sealants. In many instances, a loose correlation between mechanical properties and T_g has been observed.

With respect to the use of ATR-FTIR, it has been observed that this method does not provide useful results since it requires a near perfect contact between the ATR crystal and the surface of the sealant sample. This condition very often is not met because the surface of the degraded polymer is comparatively rough and uneven in relation to the un-degraded specimen. On the other hand, PAS is the technique of choice for sealant materials since surface roughness is not important in this technique and changes in chemical spectrum can readily be obtained using this method.

4 Proposal for standard test methods

4.1 Free-film and model joints

Free-film specimens should be used where adhesion to the substrate is not critical to evaluating the product. Specifically, this applies to those materials that are used as a jointing tape or 'Band-Aid' jointing product. Where previous trials have shown that the sealant adhesion to the substrate is likely to remain, or indeed, increase over the long-term, then the use of free-film testing is considered adequate. In all other cases, tests on model joints are preferred.

4.2 Thermal or combined ageing

Thermal ageing alone is suitable for those elastomeric sealants that have at least some sensitivity to UV radiation. Of the 16 materials evaluated in this study, the products that could be tested in this fashion include A5, A6, A7, A8, A19, A21, D24 and E25. The simplicity of thermal; ageing lends itself very well to accelerated ageing, e.g., it is possible to test these products at 120°C as opposed to the typical test temperature of 70°C. Testing at 120°C would provide a time-compression factor of 1:192 and this would permit estimating the effects of ageing over 11 years with a test conducted in 500 hours (3 weeks). The results could potentially be extrapolated to 22 years.

Combined ageing should be used for all products that have a certain higher degree of UV sensitivity. These materials include A17, A18, B9, B10, B12, B22, B28 and C23. The time-compression factor is 1:24 for tests conducted at 90°C and this implies a test time of 3000 hours (18 weeks) that would simulate ageing over about 8 years. Other possible suggestions include conducting the test over 500 hours (3 weeks) such that 2.5 years of ageing is simulated.

5 Conclusions

Considerable work has been undertaken to artificially and natural age a series of high-performance sealant products in an effort to determine test methods and test regimes most likely to simulate in-service conditions. This substantial set of result remains to be fully reviewed, however, in this report the following is apparent:

- Post-curing can take place over one year in certain materials and actual ageing appears to only take place thereafter.
- Virtually all sealants can be tested to temperatures of at least 90°C without adverse effects.

- Changes in tensile strength and elongation at break for specimens exposed to 4 years natural weathering were similar to results obtained from free-films (with the exception of 1 of 8 silicone-based materials).
- Continuous extension alone has only a very slight effect whilst artificial ageing with simultaneous extension-compression cycling has a significant and negative effect on performance indicators.
- The use of DSC appears to be the most suitable method for investigating changes in glass transition temperature (T_g) for elastomeric sealants.
- Photoacoustic FTIR spectroscopy is the technique of choice for sealant materials since surface roughness is not important in this technique and changes in chemical spectrum can readily be obtained using this method.

The research should continue such that a comprehensive assessment of different ageing regimes and their effects on various sealant products can be ascertained. This work would then provide a fundamental basis for developing useful and predictive assessment tests for sealant products currently in use.

6 References

1. Bolte, H., (1992) "Ergebnisse aus Langzeituntersuchungen elastomerer Fugendichtstoffe", in IBK-Baufachtagung 151, Hannover, 9/10, September 1992.
2. Bolte, H., Boettger, T., (1998) "Long-term stability of joints repairs in building construction", IASBE Colloquium: Saving Buildings in Central and Eastern Europe, Berlin, Germany, June 4-5 (in press).
3. DIN 50014 (1985) Klimate und ihre technische Anwendung, Normalklimate.
4. DIN 53386 (1982) Prüfung von Kunststoffen und Elastomeren, Bewitterung im Freien.
5. DIN 53504 (1985) Prüfung von Kautschuk und Elastomeren, Bestimmung von Reißfestigkeit, Zugfestigkeit, Reißdehnung und Spannungswerten im Zugversuch.
6. DIN 53508 (1977) Prüfung von Elastomeren, Künstliche Alterung.
7. DIN EN 28339 (1991) Hochbau, Fugendichtstoffe, Bestimmung der Zugfestigkeit.
8. Grunau, E.B., Esser, S., Jahn K.J. (1992), "Fugen — Auslegung und Abdichtung", expert verlag, Ehningen.
9. ISO 37 (1994) Rubber, vulcanised or thermoplastic — Determination of tensile stress-strain properties.
10. ISO 8339 (1984) Building Construction – Jointing products – Sealants — Determination of tensile properties.
11. ISO 9047 (1989) Building Construction –Jointing products – Sealants — Determination of adhesion / cohesion properties at variable temperatures.

Service life and safety prediction of concrete slabs at filling stations

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Abstract
In Germany there are almost 19.000 filling stations. Water-pollution-prevention-regulations have become stricter and in order to fulfill the new demands the bulk majority of filling stations have to renew their tanking area. Modest approximations render the tanking area of a filling station has a common size of 200 m² and the renewing costs of tanking area being DM 200/m². So the total tanking area which has to fulfill the water-pollution-prevention-regulations comes to 3,8km² and the total costs comes to 760 Mio. DM. Thus the life expectancy of concrete slabs in terms of tightness is a matter of environmental and economical importance.
In-situ tests gave the mean depth of penetration at filling stations after averagely 5 years of service less than 40mm. Non of the measured penetrations was larger than 1/3 of the existing slab thickness. The penetration at concrete/joint is not larger than in an area of concrete only. Between porosity and penetration there is a clear relationship and this relationship is stronger than of tanking operations or age of lane. Based on those tests, reference tests in laboratory and calculations the life expectancy was evaluated and found to exceed 30 years.
Keywords: Life expectancy, penetration fuels in concrete, filling stations.

1. Introduction

In a cooperation between the German Society for Petroleum and Coal Science and Technology, (DGMK), and TU-Darmstadt tests and calculations were carried out [2]. The aims of this cooperation were:

- to render a state of the art regarding the penetration of fuels at filling stations
- evaluate the life expectancy of the concrete slabs in the filling area

The evaluation of the life expectancy was based on the DAfStb - Guideline [1]. In this guideline the term tightness is defined in the following way: The penetration front of the fluidal medium does not proveably reach (with a margin of safety) the action-opposite side of the concrete structure during its time of action.

Hence uncracked concrete structures can be regarded tight when the following critera is fulfilled:

$$d \geq e_{tk} \cdot \gamma_e$$

were:
- d : thickness of concrete structure
- e_{tk} : characteristisc depth of penetration ($e_{tk} = 1{,}35 \cdot e_{t,m}$)
- $e_{t,m}$: mean depth of penetration, test result
- γ_e : safety factor for penetration

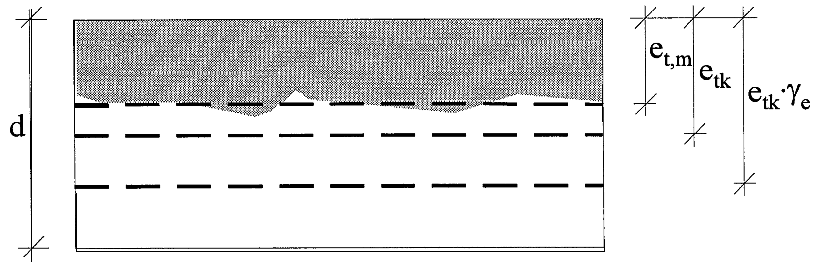

Figure 1 Defintion of tightness according to DAfStb-Guideline [1]

Knowing the penetration e_t at time t, [1] gives the following model to calculate the penetration e_{t1} at another time t_1 :

$$e_{t1m} = e_{tm} \cdot (t_1 / t)^{1/2}$$

2. Results

2.1 In-situ results

The in-situ tests were carried out at 9 filling stations numbered T1-T9. Relevant station data is shown in figure 2.

No.	location	slab size [m·m]	d slab thick. [cm]	reinforce-ment	petrol sold [l/month]	diesel sold [l/month]	date of service start	date of test	age of slab [months]
T 1	country	8,1 x 8,4	20	Q257 U	50.000	60.000	10/89	9/95	71
T 2	highway	5,9 x 3,7	20	no inform.	non	130.000	5/90	9/95	64
T 3	city	7,4 x 6,4	13-20	Q188 O+U	75.000	25 .000	10/90	2/96	64
T 4	city	4,4 x 4,5	20	Q188 o+u	97.000	15.000	11/90	2/96	63
T 5	city	4,8x5,9	18	Q188 o+u	non	30.000	6/91	2/96	56
T 6	city	5,0 x 4,2	24	2Q188 0	120.000	30.000	7/92	3/96	44
T 7	city	5,4 x 3,7	21-25	4188 o+u	non	150.000	6/92	3/96	45
T 8	city	3,5 x 3,0	21	Q188 M	non	40.000	11/91	3/96	52
T 9	city	3,2 x 3,0	18-22	non	non	70.000	8/91	4/96	56

Figure 2 Data of tested filling stations

The width of the joints was between 13 and 20 mm.The depth was between 11 and 25 mm. The mean depth of penetration was measured from bore cores taken from concrete only and the concrete at the joints of slabs. Also the porosity was measured. The results are listed for each of the filling stations in figure 3.

Filling station	Mean depth of penetration $e_{t,m}$ [mm]		Total porosity [%]
	concrete	concrete/ joint	
T 1	21	no value measured	11,3
T 2	29	no value measured	13,0
T 3	39	no value measured	11,9
T 4	15	no value measured	10,0
T 5	32	30	13,4
T 6	60	50	16,1
T 7	53	50	14.6
T 8	73	no value measured	18,0
T 9	32	32	13,6
mean $\bar{e}_t$	39	40	
Standard deviation σ_{e_t}	19	11	

Figure 3 Mean depth of penetration $e_{t,m}$ and porosity (in-situ)

The following relationships to penetration were investigated:

- porosity
- number of tanking operations
- age of lane

The penetration as a function of tanking porosity is shown in figure 4.

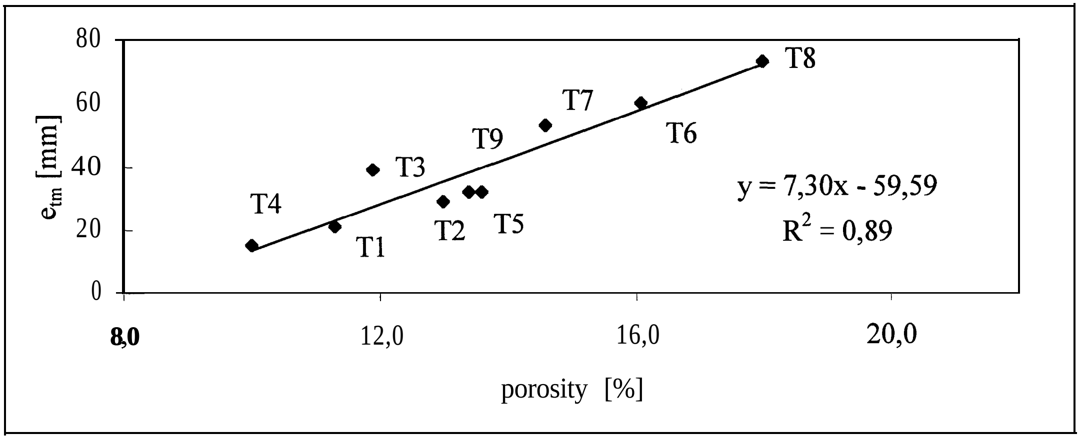

Figure 4 Penetration as a function of tanking operations

From figure 4 a clear correlation between penetration and number of tanking operations can be seen.

To evalute the effective number of tanking operations the following assumptions were made:

- the average tanking amount per tanking operation equals 40 liters [2]
- by each tanking operation the spilled amount equals 4 ml [3]

Addtionally tests made in Darmstadt have shown that the penetration of petroleum being about 0,16 times the penetration due to diesel oil. This can be explained trough the higher evaporation rate of petroleum.

Based on those assumptions and the consumption data in figure 2 the effective number of tanking operation from the date of service start till the date of testing was estimated, see figure 5.

Filling station	Tanking operations [10^3]
T 1	121
T 2	208
T 3	59
T 4	48
T 5	42
T 6	54
T 7	169
T 8	52
T 9	98

Figure 5 Number of tanking operations

The penetration as a function of tanking operations is shown in figure 6.

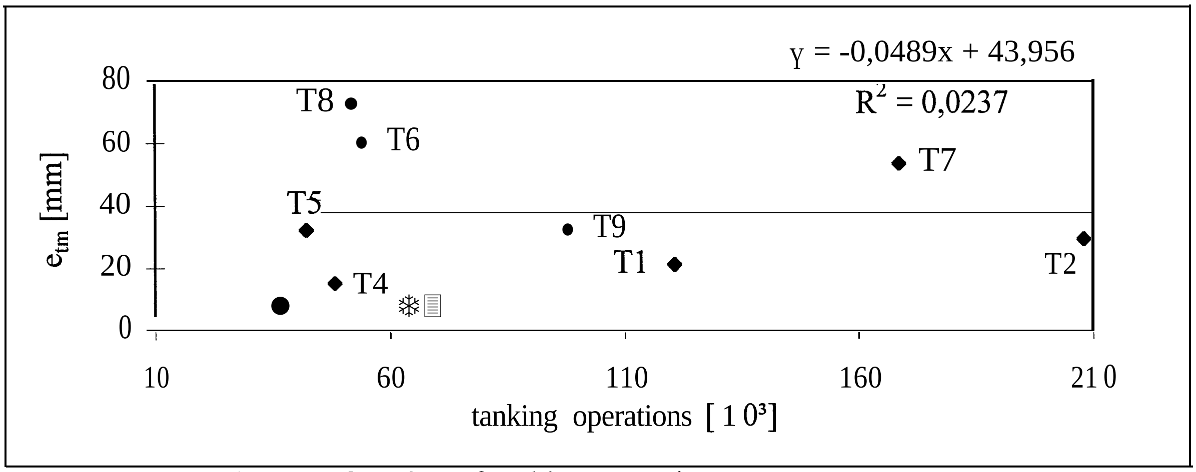

Figure 6 Penetration as a function of tanking operations

From figure 6 no correlation between penetration and number of tanking operations can be seen.

The penetration as a function of tanking operations is shown in figure 7.

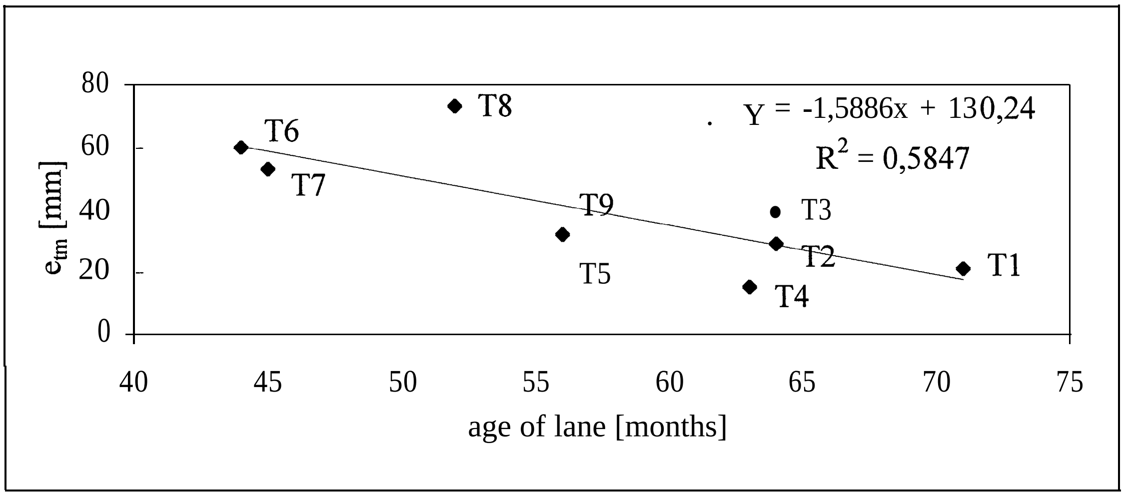

Figure 7 Penetration as a function of age of lane

From figure 7 a weak negative correlation between penetration and number of tanking operations can be seen.

Based on the results in figure 3 - figure 7 the following can be said:

- The mean depth of penetration at filling stations after averagely 5 years of service is less than 40mm.
- Non of the measured penetrations was larger than 1/3 of the existing slab thickness.
- The penetration at concrete/joint is not larger than in an area of concrete only.
- Between porosity and penetration there is a clear relationship and this relationship is stronger than of tanking operations or age of lane.

2.2 Laboratory results

A concrete was mixed, cured and acted upon intermittently according to[1]. Also an uncontamined piece of concrete was taken from filling station Tl and loaded identically. Thus a comparison between the in-situ tests and laboratory action was possible. The results are shown in figure 8.

	Depth of penetration $e_{t,m}$ [mm]					
Duration and type of fluid action	28 days each 5 hours (∑ 140 hours)		144 hours continuous		6 years tanking spillage	
Test- Medium	diesel oil		diesel oil		diesel oil/ petroleum	
Test area	concrete	concrete/ joint	concrete	concrete/ joint	concrete	concrete/ joint
Laboratory concrete	12	15	14	13	-	-
In-situ concrete T1 (no pre spillage)	20	13	15	13	-	
In-situ concrete T1 (max. spillage)	-	-	-	-	21	-

Figure 8 Mean depth of penetration $e_{t,m}$ (laboratory)

Based on the results in Figure 8 the following can be said:

- The mean penetration resulting from the laboratory action according to [1] is comparable to the penetration resulting from 6 years at filling station T1 .
- The penetration values at concrete joints are not exceeding those for continuous concrete area.

3. Life expectancy

Using the data achieved in the in-situ and labor tests and the penetration model in [1] the life expectancy was evaluated in two ways:

a) using the 5th percentiles of the penetration and the penetration model from [1]
b) using the penetration with a safety value of γ_e = 1,5 and the penetration model from [1]

The evaluation and comparison of those two different approaches is shown in the following:

a) 5th percentiles of the penetration and the penetration model from[1]

Meanvalue $\bar{e}_{t\,m}$ = 39 mm, standard deviation σ = 19 mm, number of stations n= 9

5th percentiles: $e_k^{5\%} = \bar{e}_k + k \cdot \sigma$ = 39 mm + 2,193·19 mm
= 80 mm < 200 mm (thickness of the slab)

Using the model from [1] gives:

$e_{t,m} = e_{t1,m} \cdot (t/t_1)^{1/2}$ with: $e_{t1,m}$ = 39 mm and t_1 = a

So the life expectancy, time = t, for a slab thickness e_{tm} = d = 20 cm:
$t = (d / e_{t1}^{5\%})^2 \cdot t_1 = (20\ cm / 8{,}0\ cm)^2 \cdot 5\ a = 6{,}3 \cdot 5\ a = 32\ a$

b) penetration with a safety value of γ_e = 1,5 and the penetration model from[1]

using the penetration model and the permitted value of penetration from [1] then the life expectancy, time = t, for a concrete slab of = 20 cm:

$t = (d / \gamma_e \bullet 1{,}35 \cdot e_{t.m})^2 \cdot t_1 = (20\ cm/1{,}5 \cdot 1{,}35 \cdot 3{,}9\ cm)^2 \cdot 5\ a = 32\ a$

Both approaches render the same life expectancy of 32 years.

References

[1] DAfStb: „Richtlinie für Betonbau beim Umgang mit wassergefahrdenden Stoffen" DAfStB Berlin, 1996.

[2] DGMK et al.: „DGMK-Project 478-l : „Investigations and classifications of the tightness oof the concrete slabs at filling stations", DGMK Hamburg, 1996.

[3] Scott Research Laboratories Inc. : „Investigation of Passenger Car Refueling Losses", San Bernadino, California, USA 1972.

Recycling of concrete in Sweden

Some case studies and experimental casting

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Abstract

Until quite recently, there was no recycling of reinforced concrete in Sweden. However, interest in its potential has increased significantly during the 1990s. A not insignificant number of residential buildings from 1960-75 have recently been demolished, usually in areas where there is little work. Other demolition projects have included older factories, bridges, hospitals and so on. From some of them, almost all the concrete has been completely recycled.

Most of these investigations have been financed by The Development Fund of the Swedish Construction Industry (SBUF). Development work deals with aspects such as selective demolition, transport, various applications for crushed concrete and test procedures. Optimum recycling flow rate and practical considerations are described.

A particularly interesting result is the fact that even the fine fraction of the crushed concrete can be reused for the manufacture of normal concrete grades: for example, K25 concrete was produced using 250 kg cement/m^3 with a normal dosing of plasticizer. Such concrete can suitably be made at the demolition site if new construction work is also being carried out.
Key words: Concrete recycling, demolition

1 Introduction

There is a general trend today to attempt to conserve natural resources, reduce the quantity of waste produced by society and protect the environment.

Much building waste is still disposed of unsorted in various types of landfill. Increasingly, they are being filled with large quantities of unsorted and uncrushed concrete, from which reinforcement bars are projecting. There is an increased need of sorting for reuse and reduction of gross volumes.

Environmental and natural resource considerations will make it increasingly difficult to obtain permission to open new gravel pits. The limited number of pits that do manage to obtain permission will be sited at greater distances from concrete batching plants or other points of use, resulting in higher transport costs.

In recent years, the costs of landfill disposal have risen significantly: in some local authority areas, this cost may even exceed the actual cost of demolition and transport.

It should be possible to make much greater use of crushed concrete, bricks etc. as filling material and sub-base for minor roads, factory yards, local authority facilities etc. In addition, experience from other countries indicates that the use of crushed concrete as aggregate for new concrete in building construction is very successful. In this context, this refers to the use of the coarse fraction [1].

In a number of places in Sweden there are apartment buildings, mainly from the 1960s and 1970s, which are virtually empty, leading to the creation of slums and rising maintenance costs. There are also commercial buildings, such as factories, which are not used. A common feature of them all is that they consist largely of concrete: in residential buildings, for example, concrete accounts for over 80 % of the weight.

In general, the case studies and experimental casting that have been performed have had the objective of increasing recycling and the degree of reuse of crushed demolition concrete.

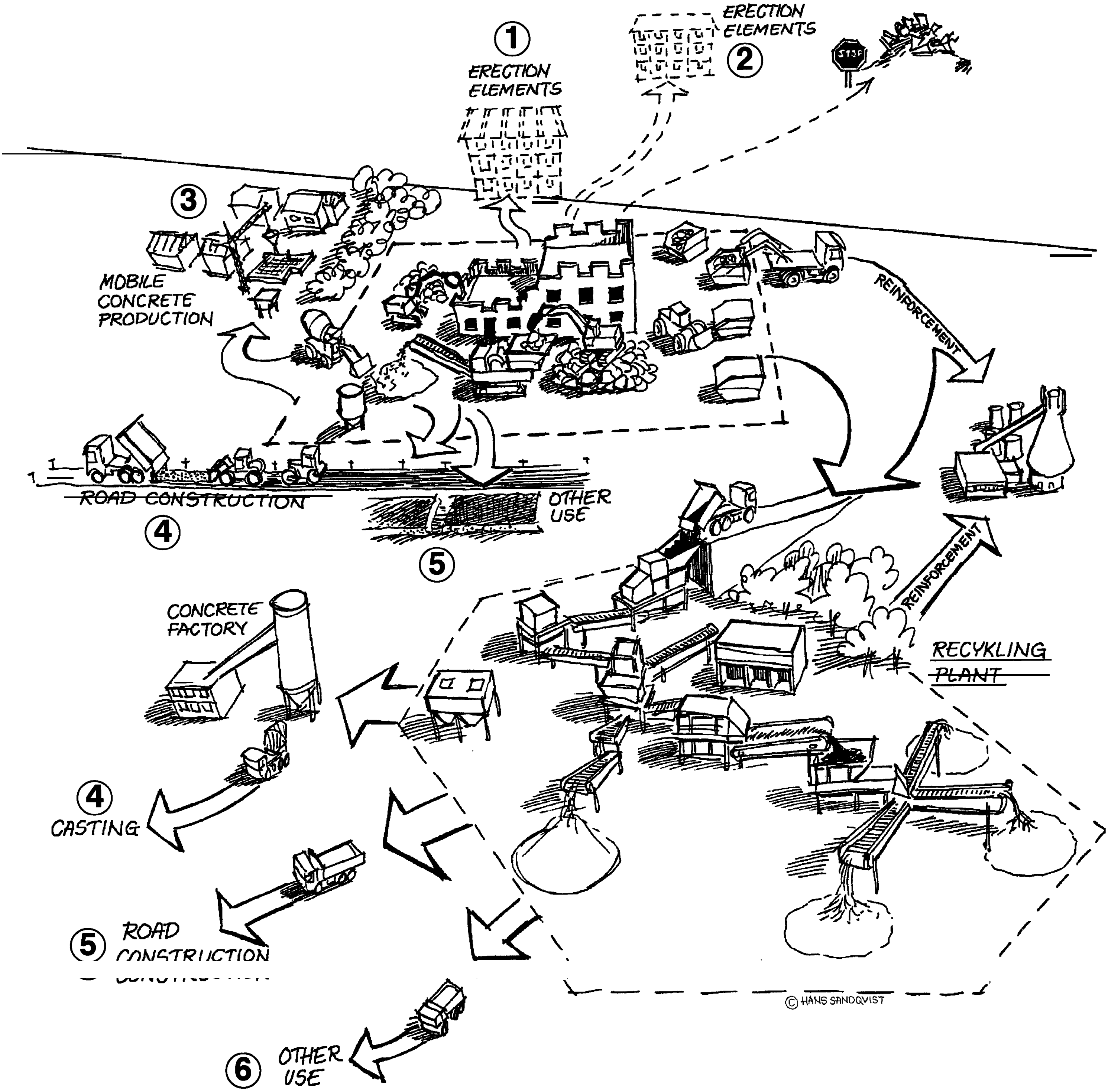
2 Case studies of demolition and reuse

2.1 A general study of a number of demolition objects

Studies of a larger number of demolition projects indicate an optimum recycling flow as follows, [2],[3]. They indicate that recycling at site or in the vicinity is preferable. In addition, efforts should be made to achieve as great a conversion of the crushed concrete as possible, i.e. preferably to produce new concrete at the site, using the crushed concrete as aggregate. This will mean that only cement will need to be transported to the site.

Crushed concrete is highly suitable for hardcore layers and sub-bases in roads, yards etc. The lowest form of recycling involves using the material as fill. If reuse at site is not possible, the crushed concrete (or larger pieces of a manageable size) and the cut reinforcing bars can be transported to a recycling plant. This will provide better opportunities for conversion, e.g. through the production of prefabricated concrete items using the recycled concrete.

RILEM's recommendations, based on experience from continental applications and a few Swedish cases, indicate that aggregate larger than 4 mm can be replaced by crushed concrete. In certain cases this will produce, for the same workability, a concrete of marginally poorer quality. It is also possible to produce new concrete in



Black arrows = Short transport
Light arrows = Distant transport

① to ⑥ = Grade of priority; ① = Higest priority which all the aggregate has been replaced by crushed concrete. However, this increases the need of water for mixing, resulting in a higher water/cement ratio and poorer quality. Such concrete can be used only for simpler purposes.

Crushed concrete is an excellent material for substrate and sub-bases in roads etc. Field and laboratory trials show that the load-carrying capacity and stability are at least as good or better than the corresponding characteristics of gravel produced from crushed rock or uncrushed natural gravel, as commonly used. However, in many cases, the grind test value specified in VÄG 94 is not achieved by crushed concrete. However, this test value is normally irrelevant for load-carrying and reinforcement layers.

Summarising, experience from a number of different types of larger demolition projects and available plant leads to the following recommendations:

1. A demolition plan should be drawn up. It should include a brief description of the project, with a clear presentation of any hazardous materials, demolition methods to be employed and the disposal of waste products.
2. The quality of the concrete must be determined in order to facilitate the maximum possible degree of reuse and processing. Characteristics such as compressive , strength, carbonation, chlorides, heavy metals and environmentally hazardous organic substances should be considered.
3. The structure of the building needs to be freed of cladding materials, roofs, windows, internal structures and building services systems. Contaminated concrete needs to be demolished separately.
4. For normal concrete buildings, having wall thicknesses less than 500 mm, demolition should be carried out primarily by cutting and/or nibbling equipment.
5. The sizes of the pieces should suit the jaw size and capacity of the crusher to be used, as well as its ability to cope with reinforcement, the thickness of the demolished material and amount of reinforcement in it.
6. Crusher size and capacity should be capable of dealing with the total quantity of demolition material to be produced. Appropriate rule of thumb guides are as follows:

- Up to about 1000 tonnes:
  Crusher weight: 15-25 tonnes
  Capacity: 50- 100 tonnes/h
- Up to about 3000 tonnes:
  Crusher weight: 25-50 tonnes
  Capacity: 100-l 50 tonnes/h
- Up to about 10 000 tonnes:
  Crusher weight: 50-80 tonnes
  Capacity: 5 1 O-300 tonnes/h

2.2 A study of a larger hospital

The demolition of a larger building on the old Långbro hospital site was selected for study for a number of reasons: partly because the purchaser, the contractor and the demolition contractor wanted to demolish the building with as little environmental impact as possible, and partly because the structure of the building was representative of a large number of concrete buildings in Sweden [4].

The building consisted of site-cast concrete with lightweight concrete insulation. The maximum height was ten floors, and the total quantity of concrete amounted to **6800** tonnes.

Under the circumstances, demolition was carried out effectively, despite the need for step-by-step selective demolition and the high proportion of asbestos and blue radon-emitting lightweight concrete. Both these materials were disposed of in landfill, despite the fact that the lightweight concrete could have been used as a filling material in groundworks.

All the crushed concrete was recycled. A smaller amount was used as aggregate in fresh concrete mixed at site in a mobile automatic concrete-mixer. Most of the crushed concrete was used for various types of ground improvement at the site and for hardcore material beneath apartment buildings. The reinforcing bars were separated as part of the crushing process and were recycled through a steel mill.

It should be clear that the greatest obstacle in the way of complete and proper recycling of concrete is the fact that it is not generally known that, in most applications, crushed concrete can replace the use of sand, gravel and macadam. There is a need for information and the drawing up of relevant performance specifications attuned to the recycling approach.

Demolition plans are needed. They should be made more detailed, so that practical problems can be foreseen before the demolition work starts. During the planning stage, it is also appropriate carefully and in detail to plan the recycling potential, preferably in the immediate area.

There is good potential for improving the efficiency of environmentally responsible demolition through the use of concrete shears. There is a need for technical development of the shears themselves, as well as for appropriate selection of the correct type of shears to suit the building being demolished.

Demolition produces considerable quantities of dust and noise, as does crushing. Resolute steps need to be taken to protect personnel and third parties from unnecessary disturbance. This means that impact-type demolition equipment should be used only where unavoidable, e.g. where it is not possible to use concrete pulverizers.

2.3 Full-scale casting with aggregate consisting only of crushed concrete

Test pieces 3 x 3 x 0.1 m were cast, producing the following quality characteristics which were dependent primarily on the methods used for reducing the water content of the fresh concrete [5].

2.3.1 Test results

Quality / method	Without vacuum or plasticizer	Without vacuum, with plasticizer	With vacuum, without plasticizer	With vacuum and plasticizer
Cylinder strength, compressive, MPa	20.8	30.3	22.3	32.7
Surface hardness, MPa	15.5	25.6	29.5	34.3
Porosity, %	33.4	28.4	26.8	25.9
Workability	2.8	4.7	2.8	4.7

1 = good workability
6 = unsatisfactory workability

2.3.2 Discussion

RILEM/1993/ gives a reason for why fine fractions in the crushed concrete are regarded as unsuitable: they often contain contaminants. This is not a problem in those cases where the original concrete is known and has been evaluated from a contamination point of view, as is the case in this particular study. RILEM also refers to inadequate documentation concerning the effect of the fine fraction on strength and durability.
Intensive work to rectify this shortcoming has started.

There is a clear benefit if the entire fine fraction can be recycled for concrete manufacture. This fraction should not cause any problem for ground reuse: if anything, the contrary applies.

The O-8 mm gravel that was investigated was very coarse, lying immediately below Curve B in the grading diagram. Here and there, the 8-30 mm stone fraction was found to contain a quantity of fines less than 1 mm, which may provide an explanation for the wide spread of the results.

There was some difference in temperature between the two pouring days, which may also explain why it was difficult to control the consistency with progressive increase in the quantity of water in order to produce the required consistency and workability. This behaviour was even more apparent with high proportions of plasticizer.

Some strength values for cube samples showed too low a strength in comparison with the cylinder compressive strength. The lowest proportion was about 60 %: 80 % would be more normal. One explanation for this could be that the very uppermost layer of concrete in the batch can easily be of somewhat poorer quality. Samples for cubes and consistency testing were always taken prior to casting the blocks. The cube value related only to one sample cube, while the cylinder value related to two samples.

The quantity of cement used was 250 kg/m^3. This particularly low cement admixture ratio was deliberately chosen in order to ensure that the investigation would produce quality results that were on the safe side, and because any minimisation of the cement content is always desirable due to the considerable contribution of carbon dioxide to the atmosphere resulting from the manufacture of cement.

High proportions of plasticizer produced surprisingly high concrete strength, and this applied particularly when a stabilising dose of glycerine was added.

2.3.3 Conclusions

- Normal concrete for use in the construction of buildings can advantageously be produced using aggregate consisting solely of crushed recycled concrete.
- Suitable applications can be simple slab on ground foundations, soleplates, walls and ceiling/floor structures.
- Transport of heavy aggregate can be avoided if the new concrete is produced in the vicinity of the crushing plant (mobile).
- Transport requirements can be greatly reduced if the recycled concrete is produced at the demolition site and if it is also used in the vicinity for the production of fresh concrete.
- Using a cement proportion of at least 250 kg/m^3 and a normal quantity of plasticizer, concrete with a strength of about 25 MPa can be produced.
- The use of plasticizer results in a significant improvement in the compressive strength.
- Vacuum application produces a significant increase in the surface hardness.
- Vacuum application significantly reduces porosity.
- Porosity is considerably higher than for concrete made with normal aggregate.

3 Acknowledgements

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4 References

1. Larsson, K., Molin, C. (1994) *Produktionsanpassad återvändningsrivning av betong och mursten. En förstudie*. SBUF, Stockholm.
2. Molin, *C.*, Larsson, K., van Meer, P. (1996) *Rivning av betong med tanke på återanvändning. Steg 2*. SBUF, Stockholm.
3. Molin, C., Larsson, K., van Meer P. (1996) *Rivning av betong med tanke på återanvändning. Steg* 3. SBUF, Stockholm.
4. Molin, *C.* (1997) *Rivning och atervinning av betong. Fallstudie av en 60-talsbyggnad*. BFR, Stockholm.
5. Molin, C., Wahlstrim, P. (1997) *Återvunnen transportminimerad betong tillverkad och brukad på platsen*. SBUF, Stockholm.

Ecological Building Design

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Abstract

In an ecological building design process, the design solutions do not only depend on the economical and functional factors but also on the environmental impact of these solutions. However, in building processes the lack of resources means that unambiguous and simplified data concerning the environmental impacts of alternative solutions should be available. In addition, design process starts from prliminary guidelines and only finally results in detailed solutions and selection of materials and products. Tools concerning the environmental meaning of different kinds of preliminary choices would be needed.

The environmental quality of a building depends on the material and energy flows during its entire lifetime. Thus the environmental requirements presented by the client should deal with the quantity and quality of energy used for heating, the service life and flexibility of the building and the envirnmental quality of building products.

In order to present environmental requirements for buildings we need to be able to focus the requirements. In addition, target values, typical values or the range of typical values concerning the energy and material flows of buildings are needed. The environmental superiority can only be assessed compared to reference values. In connection with energy saving building research, target values have been developed with regard to the use of energy, electricity and water durng the service life of buildings. However, these values should be accompanied with the knowledge concerning the environmental burdens of different kinds of energy sources.

An environmental building design process can only be successful, if it is provided with adequate design methods and tools. The most important design methods for ecological building design are energy saving design, service life design and design of flexibility and eco-based selection of building products.

Keyword: Ecological building design, environmental building

1 Introduction

In an ecological building design process, the design solutions do not only depend on the economical and functional factors but also on the environmental impact of these solutions. However, in building processes, the lack of resources means that unambiguous and simplified data concerning the environmental impacts of different solutions should be available. In addition, the design process starts from preliminary guidelines and only finally results in detailed soltions and selection of materials and products. This is why it is difficult to account for environmental data of building products and building solutions in the beginning of a design process. Tools concerning the environmental meaning of different kinds o preliminary choices would be needed.

The basic ecological criteria for buildings and building products should be the same as generally understood. This means that the basic environmental criteria for the environmental quality of the building products are the effect on the preservation of bidiversity and the adaption of activities on the natural resources and tolerance of nature.

The environmental impact of building products comes from the use of resources and the induced harmful emissions during the entire life cycle of the building products. This includes the:

- extraction of raw materials and production of products,
- procurement of energy,
- transportation, assembling and building,
- use and maintenance and
- demolition and final disposal or recycling.

However, the environmental assessment of building products is not limited to the application of LCA tools. It also requires the development of these methodologies especially with regard to the emphasised importance of service period of building products.

The environmental quality of building products does not only depend on the material and energy flows connected to the production and use of the product. It is also a function of the service life length and in some cases also of the effect of the product o the environmental burdens of the house, for example through the thermal properties of the product.

2 Environmental requirements stated by the client

The basic requirements for sustainable construction include:

- the ability of the client to present environmental requirements
- the readiness of the designer to produce a solution corresponding to the environmental requirements and
- the willingness and the ability of the producer to declare the environmental properties of products.

The environmental quality of a building depends on the material and energy flows during its entire lifetime. Thus the environmental requirements presented by the client should deal with:

- the quantity and quality of energy used for heating,
- the service life and flexibility of the building and
- the environmental quality of building products.

The majority of environmental burdens come from the energy use for heating of building spaces and water during the service life of the building. Based on this, the most important environmental property of a house is the U-value of the building envelope ad the other properties that affect the energy consumption during service life. However, if we look at the matter not only from the product-life-cycle point of view but also consider the significance of the requirements with regard to the producers of buildings and building products, it is also the environmental quality of the products that is of concerns. It is the requirements concerning the more environmental technical installation roducts and the environmental quality of other building products that sends a message to the building industry that environmental issues should be taken into account.

In order to present environmental requirements for buildings we need environmental analyses of buildings in order to focus the requirements. These analyses have been performed in several research projects. At this moment the target values, typical values or the range of typical values concerning the energy and material flows of buildings are eeded. The environmental superiority can only be assessed compared to reference values. In connection with the energy saving building research target, values have been developed with regard to the use of energy, electricity and water during the service lfe of buildings. However, these values should be accompanied with the knowledge concerning the environmental burdens of different kinds of energy sources. On the other hand, we do not have such environmental target values for building elements. In order toproduce' these, we should agree upon the basic principles of Life Cycle Inventories (LCIs) for building products, publish these LCIs and calculate typical environmental values for different kinds of building elements.

3 Building headings, indexing and LCA information

In the building sector, lists of headings for the arrangement and presentation of information used in design, construction, maintenance and repair of buildings, are agreed upon internationally. The first of such lists is the CIB Master /1/. The master lit order can be used in the preparation of many types of documents. It enables technical documents to be arranged in a consistent form. What headings are used, how much information is placed under a heading, and how far explanatory subheadings are inserted, are matters for authors, taking into account the subject, users'needs, and the purpose of the document. The CIB list (1993) includes 12 master headings, among of which are REQUIREMENTS and PERFORMANCE (behaviour of product or service in use).

Under the heading REQUIREMENTS one can refer to a regulation or other requirement, e.g. technical specification of a public authority, which the product or service is intended to satisfy. In addition, the six essential requirements listed in the Construcion Products Directive (89/106/EEC and 93/68/EEC) are:

1. mechanical resistance and stability,
2. safety in case of fire,
3. hygiene, health and the environment,
4. safety in use,
5. protection against noise and
6. energy economy and heat retention.

The Construction Products Directive states the environmental effects as an essential requirement and it also mentions the life cycle methodology as an assessment method for the environmental effects. Because of its scope it does not deal with the whole ife cycle of construction products, but only products in use.

Under the heading PERFORMANCE, the properties or behaviour in use are listed, such as structural, thermal, acoustic, service life and durability, etc.. In the Finnish version /2/ “environmental” quality is also included. A corresponding definition would also be important in the international Master List. The following addition is suggested /3/:

Environmental Quality:

Information under this heading is relevant to essential requirement 3: Hygiene, health and the environment. Attributes to be considered include: the consumption of energy and raw materials and inducing of harmful emissions during the entire life cycle, potential reuse or recycling, service life and its preconditions, and final disposal.

The building sector makes use of indexing systems of building products as product data is transmitted from producers to designers. With regard to delivery of environmental information of building products to building designers, consistent descriptions fo the products or functional units should be applied or worked out. In the European countries different kinds of indexing systems with regard to building products are used. For example in Finland “CONSTRUCTION 90” indexing is used. This indexing is composed of 10 main classes (such as surface and complementing products, electrical equipment, HVAC equipment, etc.). The main classes are divided into subclasses of three extra levels. The same kinds of systems but not identical systems are also used in other European countries. Many of those, like indexing applied in the Nordic countries and in the UK (Construction Indexing/SFB), are originally based on the SFB (Samarbetskommitte’ för byggfragor) indexing. As environmental information with regard to building products is delivered or as environmental databases of building products are planned, the indexing of the products should ideally be based on the applied systems. This is no problem within one country, but with regard to data transmission in European scale, haronised indexing is required.

4 Ecological design

4.1 Introduction

In the design process the decisive solutions with regard to materials and energy flows during the building lifetime and thus with regard to the environmental quality are /3/

the dimensioning of spaces, the design of flexibility and service life and the dsign of mechanical engineering (HVAC).

An environmental building design process can only be successful if it is provided with adequate design methods and tools. The most important design methods for ecological building design can stated as follows:

- energy saving design,
- service life design and design of flexibility and
- eco-based selection of building products.

In building process all the decisions that deal with the use of land, materials and energy affect the environmental impacts of the designed building. The required tools and systematics for environmental assessment of a building solution can thus be liste as follows:

- assessment of energy consumption (programme)
- the estimation of the energy consumption of building (assessment programme)
- the determination of quantities (calculation programme)
- the environmental profiles of fuels and electricity (data bases)
- the environmental profiles of building products (data bases) and
- a computation programme in order to calculate the environmental burdens of the whole building and its use, based on knowledge concerning the material and energy flows and their environmental profiles.

However, these tools, programmes and databases are not design tools but tools for the assessment and characterisation of the design solution.

4.2 Energy saving design

In order to formulate the requirements concerning the energy consumption and corresponding emissions, the client needs reference or target values on energy consumption of various building types.

A minimum level for energy saving building design is normally regulated by building authorities. However, energy saving design has been an object of very thorough research during the last years and design process should be provided with corresponding design methods and guidelines. Guidelines on energy saving design should be formulated so that one could consider both the energy effects and the corresponding effects on emissions already in preliminay decision making within building planning:

1 Design of building lot
- building location
- type of the building

2 Preliminary design
- architectural design
- preliminary HVAC design

3 Selection of constructions
- walls
- end walls
- party walls
- base floor
- roof constructions

- windows
- doors
- sunshades

4 Selection of HVAC systems

- heating systems
- heat recovery
- heat delivery
- ventilation systems
- water supply and sewage
- electric system
- control systems.

4.3 Connection of service life design to ecological design

Service life design methods have bee studied within RILEM, CIB and IS0 and process descriptions have been published. However, the critical issue today in service life design is the lack of information concerning the service life behaviour of building products.

The principle of service life design is to ensure that the predicted service is longer than the design life. If service life design is understood as a target aiming at the assurance of potential service life and minimising waste of materials, it can be sen as an important tool for ecological building design.

Service life is the period of time after installation during which all essential properties meet or exceed minimum acceptable values, when routinely maintained /4/. The decline in the performance of products with time may originate from physical degradation or obsolescence.

The designer should obtain the service life information from the manufacturer. From the point of view of ecological building design, the service life in years actually is less important than the adequate information concerning the conditions and limitatons for fulfilling of the potential service life (for example, service conditions and maintenance), and also the adequate information concerning recycling (possibilities to recycle and reuse, use as energy source, burning in households, etc.) or final disposal (possible obstacles for disposal on dumping sites, etc.). This information should be delivered from manufactures to designers and further from designrs to the users of buildings. Also the corresponding documents for the information transmissions should be designed and agreed upon.

4.4 Environmental selection of building products

Environmental selection of building products requires instruction files for designers dealing with building products and building elements including ecological parameters. Life Cycle Inventory (LCI) data is especially suitable for product design. However, if it is used for the selection of building products, high quality datais required. In order to use environmental information in a design process, the environmental data of building products must be simplified and unambiguous data. In order to use unambiguous environmental data of building products in design process and whe selecting building products, we should agree upon the declaration formats, the basic assessment methods and rules and the specifying of the data quality. In order to have comparable results we should agree upon the basic assessment principles concerning

- system boundaries,
- allocation rules,
- environmental parameters,
- prediction of service life,
- dealing with energy,
- consideration of effects on the energy saving of buildings,
- data coverage,
- description of data quality and
- impact assessment and weighting of results.

We should also agree upon the environmental parameters to be taken into account, such as:

- energy content,
- raw materials,
- emissions and
- other properties, such as durability and recycling.

Also the delivery and updating of data should be organised. The problems concerning this become considerably more important when building products are exported and imported.

By the initiation of the Finnish Building Industry Association (RTT) , a research project was carried out that aimed at the formulation of environmental declaration of building products /5/. Attention was paid to the “life cycle responsibility” of the producers with respect to the products. That means that the environmental declaration of building products should not only include the ecological parameters concerning the production stage, but also guidance given by the producer concerning the environmentally harmless use, demolishing, recycling and final disposal of the products. The project report includes the environmenal profiles of basic building materials produced in Finland /5/. The assessment is based on the material and energy flows reported by the producers.

The development of the environmental declarations for building materials is going on at the Building Information Institute together with VTT. The aim is to establish and publish the environmental declarations for 50 building products in Finland durig the next year. Nordic cooperation with regard to the environmental declaration of building products has started.

Another research project has also- started in Finland studying the environmental quality of technical installations and systems in buildings. The project aims at the development of the environmental declarations of building products so that the propeties of the technical installations and systems and their effect on the energy saving during the building life time can be taken into account.

Summary

The environmental quality of buildings depends in essence on the material and energy flows during its life time. This means that the environmental requirements stated by the client should concern the quantity and quality of energy used for heating and ventilation, the service life and flexibility of the building and the environmental quality of building proucts.

An environmental building design process can only be successful, if it is provided with adequate design methods and tools. The most important design methods for ecological building design are energy saving design, service life design and design of fexibility and eco-based selection of building products.

In addition, if the compliance of the building solution with the stated environmental requirements could be verified, it would help marketing new environmental and technical solutions - not as solutions as such, but as solutions enabling certain environmental properties of buildings.

References

1. *CIB Master* List. CIB Report. Publication 18. 1993.
2. *Määriteluettelot (Master Lists).* Tiula, Martti. RT and TEKES, Helsinki 1993. (In Finnish)
3. Häkkinen, T. & Kaipiainen, M. *Ecological criteria in building design and planning.* http://www.rts.fi/ecologi.htm.
4. *Prediction of service life of building materials and components.* CIB WSOIRILEM TC 71 PSL, Final report. 1987.
5. Häkkinen, T., Vesikari, E. et al. *Environmental declaration of building products.* VTT Research Notes 1752, 1997, Espoo 13 1 p.

Further steps towards a quantitative approach to durability design

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Abstract
This paper presents further steps in the development of reliability-based approaches for the durability design and service life prediction of building components which integrate the requirements of safety, serviceability and durability. In general, the load and resistance should be modelled as stochastic processes and the resulting durability problem is formulated in a time-dependent probabilistic format. Using the classical reliability approach, the resulting time-dependent reliability problem is transformed into a time-independent reliability problem through the adoption of an extreme-value probability distribution for the maximum lifetime load. The resistance degradation and its variability are included in the model, and the probabilistic design problem is transformed into a deterministic (or semi-probabilistic) problem using the first-order second moment theory. This semi-probabilistic integrated approach to durability design and prediction overcomes the shortcomings of the empirical factorial approach and the complexities of a fully time-dependent probabilistic method. An alternative approach using stochastic process theory is proposed to formulate the durability design problem as a crossing problem for which the probability of failure within the component lifetime is obtained from the first-passage probability for the stochastic process. In addition, a service life-based formulation of the durability design and prediction problems is presented in order to illustrate its equivalence with the performance-based formulation.
It is shown that in principle the same probabilistic approaches used for the development of structural design approaches for safety and serviceability are also applicable for durability design. The durability design objective is to keep the probability of failure within a specified time interval (or service life) below a certain threshold value that depends on the consequences of failure of the component or system. It is expected that in the near future, further simplifications of the proposed approaches will be made leading to practical and reliability-based methods to durability design or service life prediction. These simplified methods will be implemented in the design of durable new structures and optimal life-cycle maintenance management of existing structures.
Keywords: Crossing problem, deterioration, durability, performance, random variable, semi-probabilistic, service life, stochastic process, time-dependent reliability.

1. Introduction

The existing construction practice based on minimum initial cost and the lack of practical and reliable methods for service life prediction and life-cycle maintenance management have contributed to the significant backlog of deficient infrastructures and have inhibited any competition based on life-cycle cost optimization. This situation is worsened by the limited funds allocated for the maintenance and rehabilitation of the various infrastructure systems. Furthermore, the current design philosophy for safety and serviceability adopted by major design codes may be inadequate in certain conditions (e.g. aggressive environments) because of the assumption of the time-invariance of the resistance. Moreover, the existing qualitative ("deemed-to-satisfy") code requirements for durability are empirical with no explicit formulation in terms of performance or intended service life.

In general, the resistance of a building component is a random variable that decreases over time, which in turn, reduces the reliability and may accelerate the risk of failure and shortens its service life. In addition, the load (or action) is also a time-dependent quantity that is also random in both magnitude and time of occurrence. Therefore, a realistic modelling of both the resistance and load, and a solution to the corresponding time-dependent reliability problem require the use of stochastic processes theory. In a second stage, this time-dependent reliability problem should be simplified into a time-independent probabilistic problem. It should be emphasized that a probabilistic modelling of the durability problem will enable a rational determination of the service life or "end of life" of a component by considering both the service and economic life through life-cycle cost optimization including the costs of inspection, maintenance, repair, failure and replacement. In the last stage of the development, the approach for durability design and prediction should be time-independent and deterministic (or semi-probabilistic), in which the randomness and time-dependence of the load and resistance have been considered through appropriate probability distributions and partial safety factors (Fig. 1).

The development and implementation of such a practical approach to durability design and prediction will require calibration through extensive performance and service life data in various environments for different building components. For design and maintenance purposes, the objective is to keep the probability of failure within a given time interval (e.g. service life) to an acceptable level that depends on the consequences of failure of the building component or system. The durability design and prediction problems can be solved using either the component performance or component service life formats.

2. Existing approaches to service life prediction and durability design,

Despite the fact that thousands of papers related to material and component durability have been published over the past two decades, they had a negligible impact on the development of an effective approach for durability design [1]. Three guides for the durability of buildings have been proposed in Britain [2], Japan [3] and Canada [4]. The British and Canadian guides address qualitatively the issues of durability of structural and building envelope elements throughout the building life-cycle, while the Japanese guide (AIJ) proposes a factor-based or *"factorial"* approach for the prediction of the service life of building components. However, the use of these guides is very limited given the lack of reliable quantitative durability design and prediction procedures, in addition, no proof of the correctness of these guides has been given yet. Further, it can be added that these methods are not fully developed at a practical level. The designer/engineer using these methods may be liable for the damage due to the durability design made on the basis of these guides. For this reason, the BS 7543 is hardly used in Britain, however, the attempt of producing a durability guide is a positive development. The feasibility of the Japanese "AIJ" factorial approach for the prediction of the durability of building components has been examined [5]. The factorial approach is a simplified methodology for service life prediction in which an assumed "standard life" of a building component is adjusted by different factors that take into account the quality of the component and its incorporation within the building [3,5]. An international standard on the "*Design Life of Buildings*" is being developed by ISO/TC59/SC3/WG9, which is intended to provide a methodology for the prediction of the durability of building components based on the factorial approach [5]. In the literature, there is a limited body of work related to the formulation and solution of the time-dependent reliability design problem [8-18].

The prediction of the performance or service life of a building system and its components is a very complex problem as it depends on several factors including the loading, aggressivity of the environment, quality and frequency of maintenance, quality of materials and workmanship. Given the time-dependence and large uncertainties of the performance of building components and the associated risks of failure, it is necessary to adopt a stochastic model and use the stochastic process theory [6] for the prediction of the performance or service life at the first stage (Fig.l). At a later stage, it will be necessary to simplify this time-dependent probabilistic model into a time-independent deterministic model that has been calibrated through extensive performance and service life data (Fig.l). A practical and reliable durability design approach should overcome the shortcomings of the "AIJ" empirical factorial approach and the complexities of a full time-dependent probabilistic approach. It should be similar in format to the existing semi-probabilistic structural design approach adopted by various standards [7], i.e. the basis is probabilistic but the design approach is deterministic.

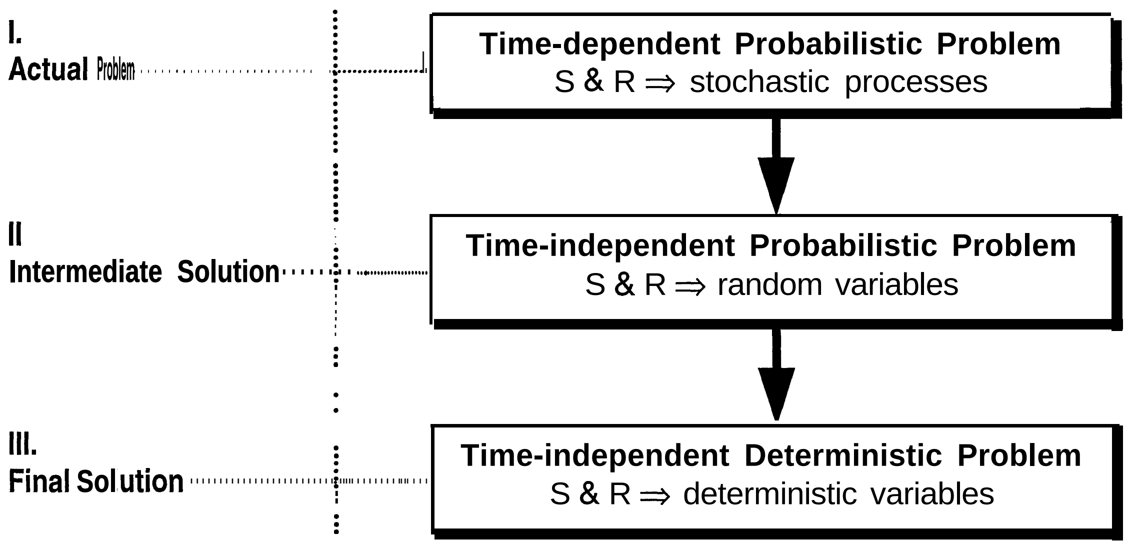

Figure 1. Development process for service-life design and prediction methodology

Such a probabilistic format will enable a rational determination of the "end of *life*" for a system or its components by evaluating both the service life (minimum performance) and economic life through life-cycle cost optimization including the costs of inspection, maintenance and failure. In addition to life cycle costing, building regulations should define the minimum reliability level for durability design based on economic and./ or legal obligations.

3. Time-dependent reliability analysis

Generally, the load (action) S and resistance R (capacity) are time-dependent random variables. Very often the load tends to increase, while the resistance tends to decrease due to deterioration induced by aggressive environmental factors, higher than expected loads or fatigue damage as shown in Fig.2. For the case of reinforced concrete structures, the most damaging environmental factors for concrete are freeze-thaw cycling, sulfate attack, alkali-silicate reactions and temperature, while corrosion due to chloride attack or carbonation is the most damaging factor for steel reinforcement. Therefore, a realistic modelling of the load and resistance requires the use of stochastic processes (Fig.2). The solution of the corresponding time-dependent reliability problem can be derived using stochastic process theory. Models for such processes may include discrete Poisson or Markov processes or continuous Gaussian processes.

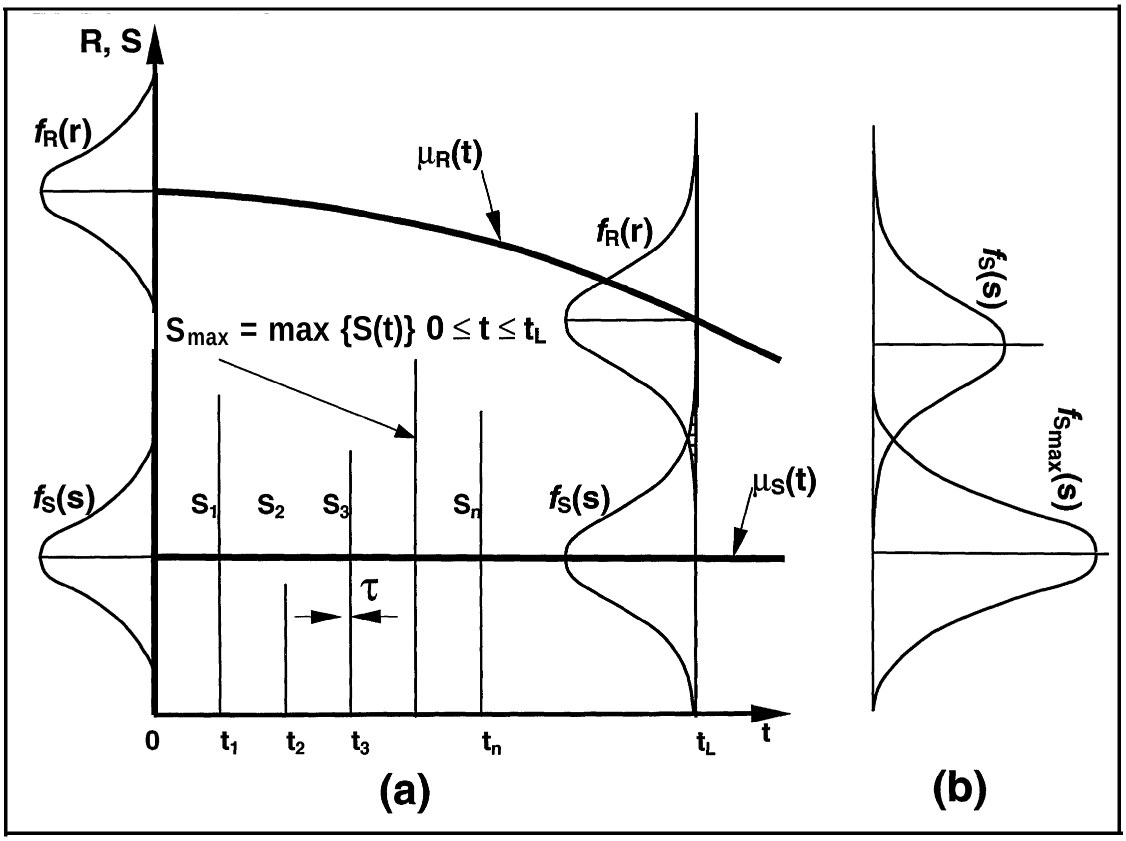

Figure 2: (a) Representation of load and resistance as stochastic processes; (b) Probability density functions of point-in-time and lifetime maximum loads

The *instantaneous probability of failure* $P_f(t)$ is defined as:

$$P_f(t) = P[R(t) \leq S(t)] \quad (1)$$

in which $P_f(t)$, R(t), and S(t) are the instantaneous probability of failure, resistance and load effect at time t, respectively. If the instantaneous probability density functions (pdf) $f_R(r,t)$ and fs(s,t) of the point-in-time resistance R(t) and load S(t), respectively are known, and if R(t) and S(t) are independent, (1) can be calculated from the following convolution integral:

$$P_f(t) = \int_0^\infty F_R(s,t)\, f_S(s,t) ds \quad (2)$$

in which $F_R(s,t)$ is the cumulative distribution function (cdf) of R(t). However, in time-dependent reliability analysis, the quantity of interest is not the above instantaneous probability of failure, but rather the probability of failure over an interval of time [O-t] or $[0\text{-}t_L]$, where t_L may represent the lifetime or service life of the structure. The determination of this probability of failure is not a straightforward task. This probability of failure can be obtained by integrating the above instantaneous probability of failure over the interval $[0\text{-}t_L]$. However, this is not possible owing to the correlation between the instantaneous probability of failure values at times t and $(t+\delta t)$ as $\delta t \rightarrow 0$, which is due to the correlation of the stochastic processes themselves [9].

3.1 Time-dependent reliability analysis using classical reliability approach

The classical reliability approach to this stochastic problem is based on the lifetime maximum load concept. It was adopted in the derivation of the probability based limit states design codes [7]. In this approach, the resistance is assumed time invariant, while the load is considered as a stochastic process. The approach is based on the fact that the structure will not fail, if it survives the maximum load S_{max}, that will occur during the time interval [O-t], which is represented by an extreme-value distribution. If the load history is modelled as a sequence of n identically distributed and statistically independent random variables (Fig.2) with cdf $F_S(s)$, and pdf fs(s), then the cdf and pdf (shown in Fig.2) of the maximum load S_{max} in the interval $[0\text{-}t_L]$ are given by [11]:

$$F_{Smax}(s) = [F_S(s)]^n \quad (3a)$$

$$f_{Smax}(s) = n[F_S(s)]^{n-1} f_S(s) \quad (3b)$$

If the number of loads n is very large, F_{Smax} asymptotically approaches an extreme-value distribution (e.g. Type I or II asymptotic forms). Therefore, the probability of failure within the interval $[0\text{-}t_L]$ denoted $P_f[0\text{-}t_L]$ is given by [11]:

$$P_f[0\text{-}t_L] = \int_0^\infty [1 - F_{Smax}(r)]\, f_R(r) dr = \int_0^\infty F_R(s) f_{Smax}(s) ds \quad (4)$$

The above integral does not contain the factor time or the number of loads n which have been included in the derivation of the distribution of the lifetime maximum load S_{max}. Hence, the original time-dependent reliability problem has been transformed into a much simpler time-independent reliability problem through the use of an extreme-value representation of the probability distribution of the maximum load that will occur during the structure lifetime. The objective in design is to keep the above probability of failure during the service life below some maximum acceptable threshold value (P_{fmax}). The value of P_{fmax} depends on several factors related to the consequences of failure such as cost of repair or replacement, risk of loss of life, importance of the component in the system, and type of failure. To simplify the computation of the above limit states probabilities in Eq. (4), first-order, second moment reliability analysis methods referred to as FOSM or FORM have been developed since the late 1960's [7,8,9,10]. The FOSM methods were used to derive the load and resistance safety factors for limit-states design of major structural design codes in North America and Western Europe. Generally, in structural design, the pdf of resistance is often considered as lognormal, while that of the load is taken as an extreme-value Type I. However, to illustrate the practicality of the FOSM approach, both R and S_{max} are assumed as having lognormal distributions. Therefore, the overall safety factor R/S_{max} has also a lognormal distribution and the limit state probability can be expressed as:

$$P_f[0\text{-}\ t_L] = P\ [R/\ S_{max} < 1] = P\ [\ln R/\ S_{max} < 0] \tag{5a}$$

$$P_f[0\text{-}\ t_L] = \Phi\ [\ln\ (\mu_R/\mu_{Smax}) / \sqrt{(V_R{}^2 + V_{Smax}{}^2)}\ ] \leq P_{fmax} = \Phi(-\beta) \tag{5b}$$

in which μ_R, μ_{Smax} are the mean values of R and S_{max}, respectively; V_R, V_{Smax} are the coefficients of variation of R and S_{max}, respectively; Φ is the standard normal distribution function; and β is the so-called reliability index. The above approximation is valid if the coefficients of variation of R and S_{max} are less than 0.3, which is a relatively low value for most practical problems in building design. The above equation can be transformed to yield:

$$e^{-\beta\alpha V_D}\ \mu_R \geq (e^{\beta\alpha V_{Smax}})\ \mu_{Smax} \tag{6a}$$

or $$\phi\ \mu_R\ \geq \gamma\ \mu_{Smax} \tag{6b}$$

The above equation is similar to the current standard equations for limit states design, where $\phi\ (=e^{-\beta\alpha V_R} < 1)$ is the understrength safety factor and ($\gamma = e^{\beta\alpha V_{Smax}} > 1$) is the overload safety factor and a is a separation function [9]. Equation (6b) represents the current semi-probabilistic load and resistance factor design (LRFD) method adopted by the structural concrete and steel design codes. This design approach is very practical because it is totally deterministic, and reliable, since the partial safety factors have been derived probabilistically by taking into account the uncertainties in the resistance and load and the consequences of failure. For the time-dependent resistance problem, where the resistance decreases with time due to material degradation, the probability distribution of interest for the resistance should be the *lifetime minimum value.* However, it is highly unlikely that the occurrence of the lifetime maximum load will coincide with the lifetime minimum resistance [9]. Within the above framework, it may be possible to model the uncertainties related to the lifetime resistance that will account for the resistance reduction with time due to material degradation. Assume that the lifetime resistance R can be expressed as follows:

$$R = D\ R_o \tag{7}$$

in which R= lifetime resistance; D = degradation factor due to aggressive environmental factors (independent of the load history); and R_o= initial resistance of the non-deteriorated component. If we assume that both R_o and D are lognormally distributed, then, R is also lognormally distributed, with a mean value μ_R and a coefficient of variation V_R given by:

$$\mu_R = \mu_D \mu_{Ro} \quad (8a)$$

$$V_R = \sqrt{V_D^2 + V_{Ro}^2} \quad (8b)$$

in which μ_D (≤ 1) is the mean deterioration factor; μ_{Ro} is the mean initial resistance; V_D V_{Ro} are the corresponding coefficients of variation. The above equations show that the mean lifetime resistance is lower than the initial value, while the uncertainty associated with it increases due to the added variability of the deterioration factor. Using Eqs. (5) and (6), and assuming the same α factor, the following design equation can be derived:

$$(e^{-\beta\alpha^2 V_D}) \, \mu_D \times (e^{-\beta\alpha^2 V_{Ro}}) \, \mu_{Ro} \geq (e^{\beta\alpha V_{Smax}}) \, \mu_{Smax} \quad (9a)$$

or $$\psi \, \mu_D \times \phi \, \mu_{Ro} \geq \gamma \, \mu_{Smax} \quad (9b)$$

in which $\psi \, [= e^{-\beta\alpha^2 V_D} < 1]$ = partial safety factor that accounts for the uncertainties in the resistance degradation due to environmental factors; $\phi \, [= e^{-\beta\alpha^2 V_{Ro}} < 1]$ = initial resistance understrength safety factor; and $\gamma \, [= e^{\beta\alpha V_{Smax}} > 1]$ =overload safety factor. Reliable data on the degradation of the resistance and its variability in different environments are required to derive reliable values for the above safety factors. The above design equation is similar in format to the current standard design expressed in Eq. (6). This is a semi-probabilistic design approach that integrates the requirements of safety (or serviceability) and durability.

3.2 Time-dependent reliability analysis using stochastic process theory

In this section, an alternative reliability-based approach to the durability design and prediction problems is proposed using stochastic process theory. As mentioned earlier, models of stochastic processes include discrete Poisson, Markov processes and continuous Gaussian processes. A problem of great importance in time-dependent reliability analysis using stochastic process theory is that of the *first crossing* by a stochastic process of a given barrier or curve. The stochastic process may represent a load S(t), and the curve may represent a strength R(t) as in Fig.2. This constitutes a so-called *"crossing problem"* [9]. The time at which S(t) crosses the barrier R(t) for the first time is the *time to failure* and is a random variable. The probability that R(t) is less than S(t) occurs within [O-t] is called the *"first passage probability"* [8,9]. The first passage probability is equivalent to the probability of failure within [O-t] expressed by Eq. (4). As pointed out in the previous section, the solution of the crossing problem is rather difficult, because the complete history of the stochastic processes within [O-t] should be considered. If the number of loads N(t) within the interval [O-t] is a random variable described by a Poisson counting process, then:

$$P[N(t)=n] = (\nu t)^n e^{-\nu t}/n! \quad (10)$$

in which ν is the intensity of the Poisson process (or mean of occurrence of the loads). The waiting time t_k for the occurrence of the k^{th} load is a random variable and is gamma distributed [8]. Therefore, the cdf $F_{tn}(t)$ for the time t_n which must elapse before the occurrence of the nth load is obtained as follows:

$$F_{tn}(t) = P\,[t_n \leq t] = 1 - P\,[t_n > t] = 1 - P\,[N(t) < n] = 1 - \sum_{k=0}^{n-1} (\nu t)^k e^{-\nu t}/k! \quad (11)$$

Of particular interest is the waiting time t_1 before the occurrence of the first load within [O-t], which is exponentially distributed and is given by:

$$F_{t1}(t) = P\,[t_1 \le t] = 1 - e^{-\nu t} \qquad (12)$$

The above equation represents the *first passage probability* [9]. If we consider a Poisson spike process as shown in Fig.2, which is defined by its intensity v (constant) and rectangular pulses of magnitude S_k and duration τ. The load S_k is a random variable independent between pulses with a cdf $F_S(s)$. The first passage probability can be obtained for the limit case as $\tau \to 0$. The probability of an upcrossing $\nu_R^+(t)$ of level R(t) is given by [9]:

$$\nu_R^+(t) = \lim_{\Delta t \to 0} \left[P\{ [S(t) \le R(t)] \cap [S(t+At) > R(t)] \}\nu \right] / At \qquad (13a)$$

$$\nu_R^+(t) = F_S[R(t)]\{1 - F_S[R(t)]\}\,\nu \qquad (13b)$$

The above equation expresses the intensity of a Poisson process and is referred to as *"upcrossing rate"* [9]. If R(t) is large, the upcrossing rate becomes:

$$\nu_R^+(t) = \{1 - F_S[R(t)]\}\,\nu \qquad (13c)$$

Using Eq. (12), the first passage probability or the probability of failure within $[0\text{-}t_L]$ is:

$$P_f[0\text{-}t_L] = 1 - \exp\,[-\nu_R^+(t)\,t_L] = 1 - \exp\left[-\{1 - F_S[R(t)]\}\nu t_L\right] \qquad (14)$$

Thus, the probability of failure is a function of the lifetime or service life (t_L) of the structure. If v is a function of time v(t), then νt_L should be replaced in Eq. (14) by $\int \nu(\tau)d\tau$. If the resistance is assumed to deteriorate with time according to Eq. (7), and if the degradation function D=D(t) is assumed independent of the load history (which is the case of deterioration due to environmental factors), and R_o is a random variable with a pdf $f_{Ro}(r)$, then Eq. (14) becomes [11,141:

$$P_f[0\text{-}t_L] = 1 - \int_0^\infty \exp\left[-\nu\{t_L - \int_0^{t_r} F_S[D(t)R_o]dt\}\right] f_{Ro}(r)dr \qquad (15)$$

An approach for durability design and maintenance is obtained by limiting the above probability to an allowable level that depends on the consequences of failure. The implementation of the above requires further simplifications to derive a practical design and prediction procedure similar to the semi-probabilistic approach in section 3.1.

3.3 Performance- vs. service life -based durability design and prediction

The probability of failure in the time interval [O-t], $P_f[0\text{-}t]$ defined above is equivalent to the event: the service life T (or t_L) is less than t [11,12,13], i.e.:

$$P_f[0\text{-}t] = P\{ R(t) \le S(t) \text{ in } [O\text{-}t]\} = P\,(T \le t) = F_T(t) \qquad (16)$$

in which the service life T is a random variable, and F_T is the corresponding cumulative distribution function. The probability density function of T, $f_T(t)$, also called the unconditional failure rate function [8,12], is given by:

$$f_T(t) = dF_T(t)/dt \qquad (17a)$$

thus $f_T(t)dt = P\,(t < T \le t+dt) = P\{ R < S \text{ in } [t, t+dt] \text{ and } R > S \text{ in } [O\text{-}t]\}$ (17b)

The hazard or conditional failure rate function $h_T(t)$, is defined as the probability of failure per unit time conditional upon survival to time t, i.e.:

$$h_T(t)dt = P\ (\ t < T \leq t{+}dt\ \mid T > t) = P\{R < S \text{ in } [t, t{+}dt] \mid R > S \text{ in } [0\text{-}t]\} \quad (18a)$$

thus: $$h_T(t) = f_T(t)/[\,1\text{-}FT(t)] = d\{\ln[1 - FT(t)]\}/dt \quad (18b)$$

For low values of FT(t) (in the order of 10^{-4}), $f_T(t)$ and $h_T(t)$ can be made equal. Using (17a) and (Mb), the following relationships are obtained:

$$FT(t) = 1 - \exp\left[-\int_0^t h_T(\tau)\, d\tau\right] \quad (19a)$$

and $$f_T(t) = h_T(t)\ \exp\left[-\int_0^t h_T(\tau)\, d\tau\right] \quad (19b)$$

The above equations show the equivalence of the performance-based and service life-based formats for the formulation of the durability design and service life prediction problems. The application of either of the two formats will yield the same solution. If failures occur purely at random, the hazard function is constant and represents an exponential distribution. However, if the failure is due to deterioration and wearing out, the hazard function increases with time, and if $h_T(t)$ increases with time as follows:

$$h_T(t) = (\beta/\alpha)(t/\alpha)^{\beta-1} \quad (20a)$$

then $$FT(t) = P_f\,[O\text{-}t] = 1 - \exp[-(t/\alpha)^{\beta}] \quad (20b)$$

which represents a Weibull distribution, where α and β are the scale and shape parameters, respectively. As discussed earlier, the derivation of a reliable design is based on limiting the above lifetime probability of failure to some acceptable threshold value that depends on the consequences of failure.

4. Conclusions

Reliability-based approaches for durability design and prediction of building components are proposed. The durability design and prediction of service life of building components has been formulated as a time-dependent reliability problem. The time-dependent reliability problem has been simplified into a time-independent reliability problem using an extreme-value probability distribution for the maximum lifetime load. The resistance degradation and its variability are included in the model, and the probabilistic design problem is then transformed into a deterministic (or semi-probabilistic) design problem using the first-order second moment theory. This semi-probabilistic integrated approach to durability design overcomes the shortcomings of the empirical factorial approach and the complexities of a fully probabilistic design method. A second approach based on stochastic process theory is developed, in which the durability design or prediction problem is formulated as a crossing problem, for which the lifetime probability of failure is obtained from the first passage probability. Durability design and service life prediction are based on keeping the lifetime probability of failure below a certain target value that depends on the consequences of failure of the component or system. The proposed approaches constitute further steps towards reliability-based durability design and prediction.

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References

1. Beeby, A.W. (1992). The contribution of research to the development of design for durability. *In Design Life of Structures*, Sommerville, G., ed., Blackie & Sons, pp. *233-239.*
2. British Standards Institution. (1992). BS 7543: Guide to durability of buildings and building elements, products and components. London.
3. Architecture Institute of Japan. (1993). *Principle guide for service life planning of buildings.* English edition, Tokyo, Japan.
4. Canadian Standards Association. (1995). CSA-S478: Guidelines on durability in buildings. Canadian Standard Association, Ontario.
5. Bourke, K., and Davies, H. (1997). Factors affecting service life predictions: a discussion paper. *Building Research Establishment Laboratory Report*, pp.26.
6. Ross, S.M. (1996). *Stochastic Processes.* John Wiley & Sons, 2nd Ed., New York.
7. Ellingwood, B.R., MacGregor, J.G, Galambos, T.V., and Cornell, C.A. (1982). Probability based load criteria: load factors and load combinations. *ASCE J. Struct. Engrg.*, Vol. 108, No. (ST5), pp. 978-997.
8. Madsen, H.O, Krenk, S, and Lind, *N.C.* (1986). *Methods* of *Structural Safety.* Prentice Hall, Englewood Cliffs, NJ.
9. Melchers, R.E. (1987). *Structural Reliability-Analysis and Prediction.* Ellis Horwood Ltd., Chichester, England.
10 Schneider, J., et al. (1996). Variables processing- Vorträge. Tagungsunterlagen, Institut für Baustatik und Konstruktion, ETH, Zurich.
11. Freudenthal, A.M., Garrelts, J.M., and Shinozuka, M. (1966). The analysis of structural safety. *ASCE J. Struct. Div.*, Vol. 83, No. ST4, pp. 267-325.
12. Kraker, A., Tichler, J.W., and Vrouwenvelder, A.C.W.M. (1982). Safety, reliability and service life of structures. *Heron*, Vol. 27, No. 1, pp. 88.
13. Siemes, A.J.M., Vrouwenvelder, A.C.W.M., and Beukel, A. (1985). Durability of buildings: a reliability analysis. *Heron*, Vol.30, No.3, Delft, The Netherlands.
14. Mori, Y., and Ellingwood, B.R. (1993). Reliability-based service life assessment of aging concrete structures. *ASCE J. Struct. Engrg.*, Vol. 119, No.5, pp. 1600-1621.
15. Sarja, A., and Vesikari, E. (1996). Durability design of concrete structures. *RILEM Report* 14, E & FN Spon, London, pp. 165.
16. Siemes, A.J.M. (1996). Framework for a procedure for design for durability. *Durability of Building Materials and Components 7*, Vol.2., E & FN. Spon, London, pp. 1175-l 184.
17. Mirza, M.S., and Lounis, Z. (1996). Design of concrete structures for durability-a state-of-the-art report and framework. *International Colloquium on Structural and Geotechnical Engineering.*, Cairo, Vol. 2, pp. 1-18.
18. Comité Euro-International du Béton. (1997). New approach to durability design. Bulletin d'information No.238, Lausanne, Switzerland.

Improving building operators contribution towards sustainability

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Abstract

The growing understanding regarding limitations of natural resources together with a better knowledge of relations between building, urban and environmental quality provides for new initiatives to improve the building process. In particular, these new initiatives are focusing on developing concepts and proper approaches in support of sustainable development.

To attain this goal, the roles and tasks of the various operators, i.e. designers, constructors, managers, surveyors, etc., must be revised and as well general principles must be translated into specific practical instructions.

The current research focus consists of providing guidelines, suggestions and case studies for the planning, design, construction and the selection, use and re-use of materials towards achieving sustainability in construction.

In order to single out the best design decisions to attain sustainability requirements, the creation of a database to store solutions applied in different contexts would serve many useful purposes.

In this framework the Internet plays a significant role as a "mine" of information. However, with the rapidly growing number of Web sites, it can be very difficult to locate what it is needed; on one hand time is wasted in unproductive navigation and on the other hand, a lack of transfer and communication of available data there still exists.

A productive search needs good planning and knowledge of the proper tools to use. The paper presents the first results achieved in information retrieval on the Web, using intelligent agents and specifically related' to sustainable construction. The results are available on the web site "Sustainable Building Resource" (http://area.ba.cnr.it/iris/sustain) a "clearinghouse" for information, applied research, and Internet links about basic principles of sustainable design.

Keywords: Sustainable building, Building Design, Design for Durability, Internet

1 Introduction

The growing interest in sustainability is widely highlighted by various definitions that appear in the technical literature. The understanding of what the sustainable development is and of how it can be pursued in the building design practice necessarily requires the translation of the various general principles already set in more fields (economics, energy, industry, politics, etc.) into specific goals and operative criteria with reference to the roles the different categories of operators have to carry out.

In order to single out the best design decisions towards the sustainability requirement, the creation of a database in which to store examples of solutions already applied by designers in different contexts would serve many useful purposes.

Very useful as well seems to be the systematic analysis and optimization of the whole buildings' life-cycle taking into the due consideration the materials used in the construction, the disposal of their debris, the management, maintenance and the final destination of the building at the end of its service life.

The effective management and circulation of such data demands innovative information technologies; consequently, the research here presented has been focused on the Internet both as a mine of information and as an ideal and very accessible channel for communication and information exchange.

2 The Survey on the Internet

The rapidly increasing use of the Internet is creating a more and more complex computing environment: sources of information are augmenting together with their content; very many news (study and research reports, articles, etc.) are available but the Internet users have to figure out how to find them.

Surfing the Internet is a technique equivalent to looking for information in a library without using the catalog. You can use this technique effectively only when you've found a group of pages that are related to the topic you are researching. The WWW Virtual library (http://vlib.stanford.edu/Overview.html) is a noticeable starting point. Once you have found a contents page related to your topic, you may wish to follow each of the links to each of the pages in search of valuable information.

Other sources of information are newsgroups (collections of discussions related to certain topics). To find the names of relevant newsgroups, you can visit http://www.tile.net/ or http://www.dejanews.com/home_bg.shtml.

Search Engines are usually the quickest way to locate information on the Internet. These engines are free to use, because they are supported by advertisers who post banners on the search result pages. Most of such engines use a complex algorithm or set of calculations to analyze the web pages. The results they deliver depend on what the engine "thinks" it is the most relevant. However even with a tightly focused search statement it is possible to get hundreds of documents in answer. The available search engines differ for the type of search they can perform. The consequent substantial difference in their search results marks out the need to use all the available engines.

So we are testing the use of search agents, an emerging technology that help to do things like find and filter information, customize views of information, automate the information research work. Unlike the search tools, the agents are software applications to buy, install, and run from the desktop. It is possible to enter the search query offline, and then the agent runs it through anywhere from half a dozen to 30 or more individual search engines at a time. Instead to visit each search site in turn, the agent query the resources, collect the responses and present them on a single page (Figure 1).

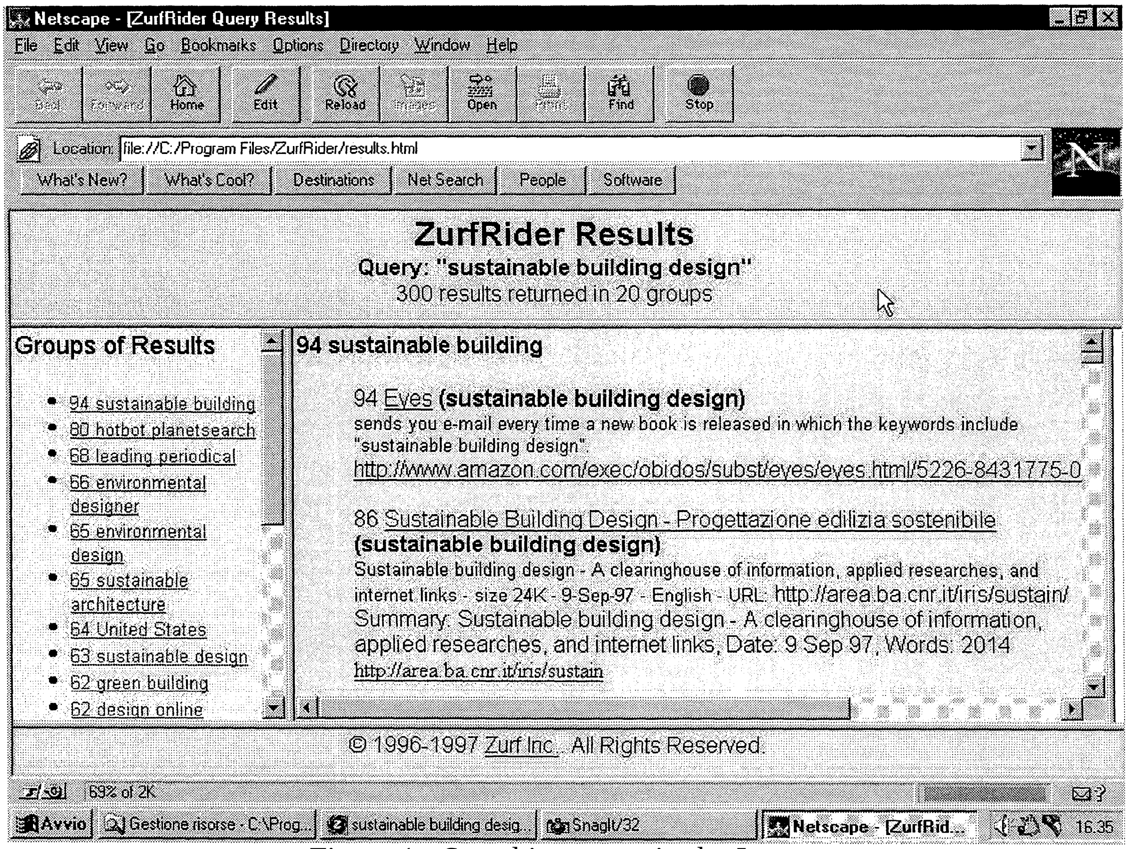

Figure 1 - Searching agent in the Internet

3 Sustainable Design and Construction

Our survey on the Internet shows that not all countries share the same views about sustainable building, and that the amount of attention to the various topics varies greatly (Table 1). For this reason the different approaches have been grouped and classified on the basis of their essential features, as a necessary first step towards the building of the database [1]. A first analysis of the search results shows that building design can provide good contributions to the sustainability in the following ways:

- meeting lower energy requirements;
- bringing down the life-cycle costs of the components to be used;
- making a wide use of renewable resources and materials;
- adopting technologies for passive energy behaviour;
- combining a wider use of renewable resources and a more efficient use of the non-renewable ones, probably the best way to pursue at the moment;
- using appropriate technologies;
- involving all the categories of building operators in the goal.

Sustainable architecture Environmental architecture	Building design strategies represent only one of the steps towards the building of a sustainable community. In the most radical approaches is exclusively allowed the use of renewable resources and passive technology (www.arch.wsu.edu/information/sustain/home.html))
Sustainable Building Sustainable Construction Environmental building	The main goal is the minimization of building environmental impact by the identification and the choice of adequate technologies. The building is analyzed during its life cycle: from the extraction of raw materials, to the phase of construction and demolition (sustbuild.chalmers.se/progplan.htm) The optimization of the building environmental performances can be gained utilizing renewable resources or utilizing efficiently the non-renewable ones. At the same time the design process requires the participation of all actors involved (www.bmg.kt.se/www/bmg/baoh/eaob/htm).
Sustainable design Sustainable building design	In this approach sustainability is considered not only as a technological problem, but also as a requirement of classical design principles and concepts such as standard and final users. Refusing conceptual generalization the context becomes the real base for defining design criteria (greenbuilding.ca/setpoint.html).
Green design Green building	The reference point is the minimization of the environmental impact linked to building construction and rehabilitation. Particular attention is paid to the use of natural resources. Green can mean both utilizing recycled materials or efficient energy use or efficient use of resources and as a process. In this case, it starts with the risk detection linked to the design and the selection of those that must be minimized. Then the proposed design alternatives are selected considering, among evaluation criteria, the client economic requirements (greenbuilding.ca/abn12epg.html)
Built environment Environnement construit	Buildings are studied from a multidisciplinary perspective referring to the building technologies or to the relationships between building and environmental components such as the social and the economical ones: -performance systems which meet the environmental or users requirements (envist .cmu.edu/research/built.html); -housing typological transformations in a specific social context (dawww.epfl.ch/info/recherche/irec/textel.html)
Architettura bioecologica Bioarchitettura	The bioarchitecture can be seen as the cultural root of the ecological study of building and environment relations the objectives is to plan in order not to alter the ecological equilibrium of the place that is taken as an essential reference in the design (www.vol.it/ABRUZZO/BIOARCHITETTURA/leggi.html)
Appropriate Technologies	Here the principal commitment consists in promoting the use of appropriate technologies, above all in developing countries where the main characteristics are in the course of being identified (obelix.polito.it/forum)
Earth architecture Bioconstruction	Building system utilizing earth and renewable materials (www.ran.org/ran/ran _campaigns/rain _wood/wood con/earth_arc.html)

Table 1 - Searching in the Internet by keywords

Although a considerable amount of energy can be saved by resorting to innovative solutions (e.g. bioclimatic architecture, advanced building materials) at present it appears to be more appropriate to focus on strategies not interfering with traditional building methods [2].

In this Design for Durability, the new discipline that deals with the optimization and innovation of the design choices to meet service life requirements can provide great contribution to sustainability by a more efficient use of the traditional building materials and a proper use of innovative, renewable materials.

The building design can in fact incorporate sustainability principles effectively and economically by adopting solutions suitable to reasonably produce appreciable benefits. In table 2 a list of sustainability goals associated to lists of relevant solutions already tested in building works carried out in different countries is presented [3]. This table highlights a significant part of the concrete and simple possibilities to reduce nowadays the impact of buildings still to be designed. It can also stimulate further research of new solutions with higher sustainability by designers.

	GOALS	POSSIBLE SOLUTIONS
DESIGN	reduction of non-renewable materials consumption	reduction of «virgin» wood consumption (reuse of wood and lumber) materials life-cycle analysis[a]
	reduction of non-renewable energy consumption	use of materials with low embodied energy use of simple assemblage systems use of «passive» solar design technologies [b] collection and filtering of rainwater for domestic use [c] collection and reuse of gray water for irrigation’“’ collection and treatment of sanitary wastes for the production of methane gas and fertilizers [c]
	reduction of construction costs	use of locally available materials (reduction of transportation costs) use of «humble» building techniques (reduction of costs)
	minimization of impacts on air	use of non-polluting materials
	improvement of the human well-being in building	use of low voltage current generation systems (photovoltaic cells) «active» use of vegetation [d]
CONSTRUCTION	reduction of construction waste production	ordering of products with minimal packaging selling back of exceeding materials to producers ordering of products in fixed dimensions reuse of moulds (and reselling of scrap wood) reuse of excavated soil
	reduction of demolition waste production	pre-selection and registration of waste materials (previous evaluation of quality and quantity of materials) «in-situ» separation of waste materials
	minimization of impacts on soil	previous specification of areas for the storage of materials minimization of deforestation minimization of soil disturbance caused by excavation minimization of access roads construction
	protection of aquifer system	prohibition of the collection of rainwater
	minimization of impacts on watercourses	deviation of waste water and collection into absorption trenches use of rainwater
	minimization of impacts on air	use of non-polluting materials

(a) the development of models for life-cycle evaluation is one of the objectives of the ((Waste and Recycling - Cleaner Technology 1993-97» Plan (Danish Minister of Environment)
(b) solar panels, photovoltaic cells, natural ventilation, materials with great thermic inertia
(c) goals accomplished by a foundation system consisting of separate interlocking lightweight concrete containing the processing and storage equipment necessary to supply the utility necessities
(d) employment of the electrochemical properties of plants to improve air quality.

Table 2 - Possible solutions to incorporate sustainability in building

The economic limits are typically one of the main concerns in the design stage together with the reduction of the consumption of nonrenewable materials and energy. The latter is also the ultimate goal of several national laws and of the E.U. directives as well. In the construction stage, sustainability can be pursued securing appropriate maintenance and protection from the deterioration agents of the exposure environment.

Also the re-use and the recycle of building materials allows the cut down of the consumption of non-renewable materials and energy and the consequent reductions of the materials' disposal and of the relevant costs.

Information, applied research, and Internet links on the basic principles of sustainable design are available on the web site "Sustainable Building Resource" (figure 2). The site aims also to promote an Internet ring to share knowledge and information about sustainable building. People interested in this campaign are invited to insert a special banner in their web page (figure 3), in order to put a link with the web pages that have been marked in "Sustainable Building Resource" (the banner can be copied directly at http://area.ba.cnr.it/iris/sustain/ring.htm). Site to site links, in fact, increases the probability that a web site can be found; it may bring in much more meaningful traffic than indexing the site by search engines.

4 Sustainability and Design for Durability

Sustainability has to be intended as the final goal of the work in the field of durability and therefore a key issue of Design for Durability, the new discipline that deals with the optimization and innovation of the design choices to meet service life requirements.

A good practice of the planning, design and management of buildings' service life can in fact guarantee - and has to - a significant saving of natural and not renewable resources.

Design for Durability can effectively incorporate sustainability in very many ways. Looking for instance at the selection and use of materials:

- improvement, where this is globally advantageous (coherence with architecture, design service life, transportation distance, etc.) of the use of renewable materials;
- improvement of the engineering of the building design e.g. increase of the dismountability and recyclability of building elements; reduction (i.e. optimization) of the quantities of the not renewable materials (nowadays with a better design: shapes, thickness, mix-design, reinforcements, etc. and execution it is possible to realize concrete structures 20 - 30 % lighter but with the same structural performances of the more traditional and heavy; obviously it requires to invest much more on the detailed design, on the quality of materials and on the practice accuracy);
- organization of stocks and databanks for dismantled materials;
- rationalization of the transportation of building materials;
- characterization of the functional characteristics of building materials (for service life design) together with information on the impact of their production (quantity of energy, recycled parts, recyclability, etc.).

As to the improvement of the building performances which can contribute to a better environment:

- less heating and especially less air conditioning to get the same comfort conditions;
- better natural lighting;
- more vegetation;
- less defects;
- more protection and better conservation of the parts which are more stressed: roofs, claddings, etc.

Looking at the building operators:

- better education of all the practitioners and building operators with regard to the planning, design and management of buildings' service life and to the building's environmental impact.

Many other items can be added and developed in the next future still remaining in the field of building service life planning, design and management.

5 Conclusions

Building design can provide good contributions to the sustainability of the whole building process. Building design can incorporate sustainability principles effectively and economically by adopting solutions suitable to reasonably produce appreciable benefits.

The Internet plays a significant role, as a mine of information and as a great platform for electronic publishing useful to building designers as well.

By the use of search agents to find and filter the technical information available on the Internet it is easier and takes less time. This has been tested in a research sponsored by the Italian National Research Council as illustrated in the paper.

Also Design for Durability, the new discipline that deals with the optimization and innovation of the design choices to meet service life requirements, can provide great contribution to sustainability by helping the designers to make a more efficient use of the traditional building materials and a proper use of the innovative, renewable materials.

6 Acknowledgements

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7 References

1. Maiellaro, N., Monno, V., Sharing Sustainable Building Knowledge, Paper accepted for IAHS World Housing Congress 1998, Lisboa, Portugal.

2. Friedman, A., Cammalleri, V., (1994), Reducing Energy, Resources and Construction Waste through Effective Residential Unit Design, *Building research and information 22 (2),* 103-108

3. Maiellaro, N., Lerario, A. (1996), Sistemi per la conoscenza come supporto alla progettazione sostenibile, *seminario internazionale Sostenibilità ambientale: approcci urbani e regionali,* Otranto, 16-l 8 maggio, 53 8-55 1

Degradation of Portland cement and Portland ash cement concrete

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Abstract
Degradation of concrete, as well as the related protection and ensuring of concrete structures against aggressive impacts by chemical agents, regardless whether this concerns liquid, gas or even solid phase under certain conditions, represents a complex problem of utmost importance for the economy in general, and especially for building construction and the construction industry.

Japanese researchers Matsufuji, Koyama and Harada proposed an estimation equation which can be used to predict the progress of deterioration for various building materials, and an attempt is made to summarize and classify the deterioration phenomena of each material used in a building. This equation give the degree of degradation in the function of the environment where materials are exposed, properties of deteriorating parts and degradation process time.

This paper shows the utilization of proposed equation with the influence by the composition of Portland cement clinker and of cement, on the degradation of cement stone by the impact of the aggressive environment. Solution of ammonium sulphate was selected as the representative of the aggressive environment, bearing in mind that in nature these ions are frequently encountered in underground waters which come into contact with concrete.

The results showed that there is a considerable compliance of the got results with the proposed model for the prediction of degradation process.
Keywords: Degradation, concrete, Portland cement, fly ash

1 Introduction

Chemical degradation of concrete is the consequence of reactions between the constituents of cement stone, i.e. calcium silicates, calcium aluminates and above all calcium hydroxide, as well as other constituents, with certain substances from water, solutions of soil, gases, vapours, etc. The most important aggressive agents are: SO_4^{2-}, Mg^{2+}, NH_4^+, Cl-, H+, HCO_3^-[1-3].

When we speak about sulphate degradation, we primarily think of the impact by sulphate ions on cement stone. The sulphate ion is the cause of one of the most dangerous corrosions - the corrosion of expansion and swelling - because it causes the occurrence of expansive compounds, first of all ettringite- $C_3A{\cdot}3CaSO_4{\cdot}32H_2O$, in the shape of prismatic crystals.

For the process of concrete degradation under the impact of sulphates, it is essential which cation is linked with the sulphate ion. Namely, cations linked with sulphate ions can be divided into three characteristic groups. The third group of sulphates, that is $(NH_4)_2SO_4$ and H_2SO_4, covers the most aggressive compounds. In case of impact by these compounds on concrete, neither balancing nor creation of protective gel takes place. The destruction of concrete, in this case, occurs not only due to expansion, but also because of intensive dissolution of cement stone.

1.1 Proposed degradation model

Japanese researchers Matsufuji, Koyama and Harada [4] proposed an estimation equation which can be used to predict the progress of deterioration for various building materials, and an attempt is made to summarize and classify the deterioration phenomena of each material used in a building.

Environmental forces have a direct effect on deterioration together with gases and liquids, which also have an indirect effect. Those deterioration factors are defined as environmental factors contributing to deterioration.

Generally, the deterioration of building materials progresses as the environmental factors permeated and otherwise affect the materials. An estimation of deterioration is shown in Figure 1 with the assumption that the environmental factors, which act on defect-free internal parts, are influenced by the property of the parts that have already deteriorated.

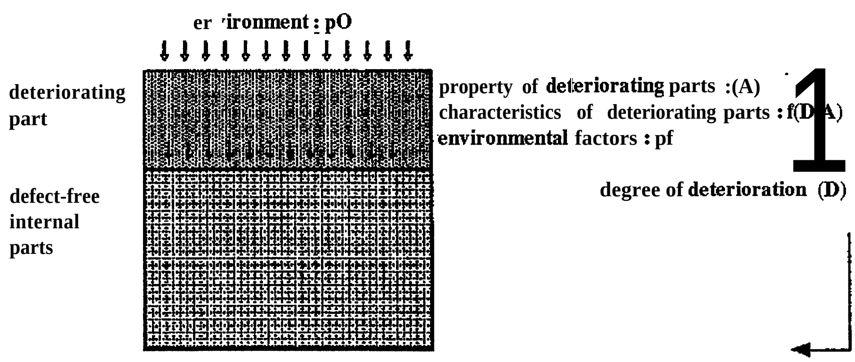

Fig. 1 An estimation of deterioration

The affect of the environmental factors (*pf*) depend on the environment where materials are exposed (*pO*) and the characteristics of the deteriorating parts between *pO* and *pf*. Also, the characteristics of the deteriorating parts can basically be presented by the function (*f(D,A)*). D is the degree of deterioration of the material itself and *A* is the property of the deteriorating part. As the result, pf can be represented as shown:

$$pf = pO + f(D,A) \qquad /1/$$

If we assume that the deterioration speed is proportional to pf, the diferential equation representing the deterioration speed (*dD/dt*) will be as shown in Equation /2/

$$dD/dt = k\ pf \qquad /2/$$

k is the constant for proportion.

Further, if we assume that the characteristic values of deteriorating parts, *f(D,A) can* be represented as the product of the degree of deterioration and the deteriorating material, Equation /3/ can be obtained from Equation /2/.

$$dD/dt = b + aD \qquad /3/$$

dD/dt is the deterioration speed.
b is a constant related to *pO*.
a is a constant related to the properties of deteriorating parts.

From Equation /3/, considering that *D-O* at time *t=O*, the degree of deterioration (*D*) can be represented as shown in Equation /4/ and Equation /5/.

at time $a=O$, $D = b\ t$ /4/

at time $a \neq 0$, $D = bla\ (exp(at)-1)$ /5/

where *D* is a degree of degradation,

a is a constant depend on the environment where materials are exposed,

b is a constant related to the properties of deteriorating parts,

t is degradation process time.

The above results can be represented as shown in Figure 2 and the deterioration of building materials can be classified into the three patterns shown below according to the value of *a*.

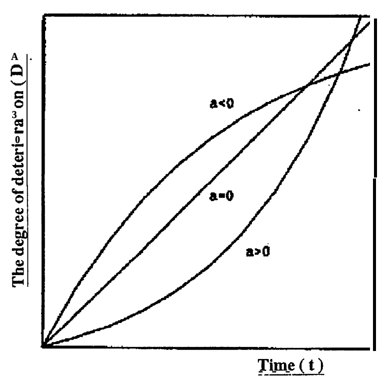

Fig. 2 The deterioration patterns of building materials

a) Alignment type: when $a=0$

In Equation /3/, when $a=0$, the deteriorating parts do not affect pf even if deterioration has progressed. Accordingly, the deterioration effects on building materials can usually be considered to equal pO. In this case, deterioration speed does not depend on the current status of deterioration, so it is the simplest model for the estimation.

b) Convergence type: when $a<0$

When $a<0$, the speed of deterioration depends on the current degree of deterioration, but the speed is falling gradually. That is, the deteriorating parts reduce external force causing deterioration. In this type of deterioration pattern the speed of deterioration increases at the beginning and is zero at the end.

c) Multiplication type: when $a>0$

When $a>0$, the speed of deterioration depends on the current degree of deterioration. In this type of deterioration pattern, the more the degree of deterioration progresses, the higher the speed becomes.

Bearing in mind all the above-mentioned, the basic idea and motivation for the work on this paper is to wide the knowledge so important for the prediction of the construction life-time and sustainable construction [6-10].

2 Experimental

The programme for researching degradation of cement by the impact of sulphate corrosion envisaged characterization of Portland cement and Portland fly ash cement manufactured in our country:

- Portland cement 1 (PC1)
- Portland cement 1 with the addition (replacement of clinker) of 30% of fly ash (PAC 1)
- Portland cement 2 (PC2)
- Portland cement 2 with the addition (replacement of clinker) of 30% of fly ash (PAC2)

Complete testings of the chemical composition of all materials were carried out, same as the testings of physico-chemical and mechanical properties of cements, and the potential phase analysis of clinkers was given. In the second part, the testings of the influence by the selected aggressive solution on concrete were carried out.

2.1 Method for testing the influence of aggressive environment

The 10% solution of ammonium-sulphate was used as the aggressive environment according to the Koch-Steinegger's method [5], to the influence of which cements were exposed. This method was selected as the basic procedure in determining corrosion degradation of cements. Exceptions of the method were made by testing after 7, 14, 28, 56, 90, 180 and 270 days instead of usual testing terms.

Results were presented by the mass change of the testing samples through time, by bonded SO_4^{2-} content calculated from the SO_4^{2-} content in solution, and by the degradation coefficients which were calculated as supplement of the corrosion coefficients of the testing samples.

2.2 Other testing methods used in this work

1. Determining the strength (EN 196-1)
2. Chemical analysis (EN 196-2)
3. Determining the setting time (EN 196-3)
4. Determining the sieve residue (EN 196-6)
5. Determining the specific surface (EN 196-6)
6. Calculating the potential mineralogical analysis (ASTM C 150)

3 Results and discussion

The selected aggressive environment represented very strong aggressiveness to ensure fast results for the real conditions which can be present in underground waters in the territory of our country.

The potential phase analysis, for the Portland cement clinkers is given in Table 1. It can be seen that used kinds of cement differ on the percentage content of C_3A in clinkers 6.60% to 13.3 1%, which has its impact regarding sulphate resistance. The difference in the C_3S content was significant regarding sulphate resistance also.

Potential phase composition, % mass	Portland cement clinker 1	Portland cement clinker 2
C_3S	57.54	66.98
C_2S	13.50	12.72
C_3A	13.31	6.60
C_4AF	8.67	9.10

Table 1 Potential phase composition of portland cement clinker

Chemical composition,% mass	Fly ash
LO1	5.68
SiO_2 + Al_2O_3 + Fe_2O_3	84.06
CaO	6.52
MgO	2.65
SO_3	0.05
S	0.02
Na_2O	0.30
K_2O	0.70
Insoluble residue	76.61

Table 2 Fly ash chemical composition

Table 2 presented the chemical composition of mineral admixture - fly ash. Fly ash, by its chemical composition, shows traditional ash, which makes it relatively suitable for application in concrete (suitable content of the sum of oxides SiO_2, Al_2O_3 and Fe_2O_3, and the low content of CaO also). MgO, sulphate and alkalies content were low also.

As regards the chemical composition, physico-chemical characteristics, flexural and compressive strengths all the cements satisfy the conditions for quality of the Yugoslav standard JUS B.C1.011.[7-9].

In this way, complete characterization was implemented regarding all the cements used in this work. The results of testings of the impacts by aggressive solution, that is, the degradation by sulphate corrosion of cements, carried out in line with mentioned method, are presented, by mass change, bonded SO_4^{2-} content and degradation coefficients, in Figs 3 to 8.

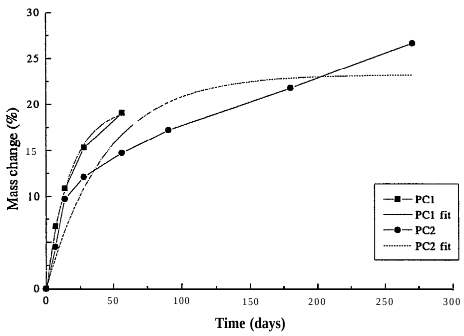

Fig. 3 Experimental and estimated curves for mass change for Portland cements

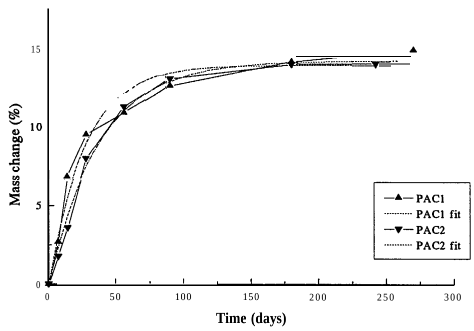

Fig. 4 Experimental and estimated curves for mass change for Portland ash cements

Figs 3 and 4 presented mass change of concrete testing samples exposed to the aggressive ammonium-sulphate solution. Curves PC1 fit, PC2 fit, PAC1 fit and PAC2 fit presented estimated curves from Equation /5/ for the mass change.

Due to fast mass change and ettringite formation PC1 testing samples lasted for 56 days only, but PC2 testing samples lasted for whole 270 days. It is obvious that C_3A clinker content played important role. Cements with the ash addition lasted for 270 days also, confirming that ash played protective role against ammonium-sulphate solution aggressive impact.

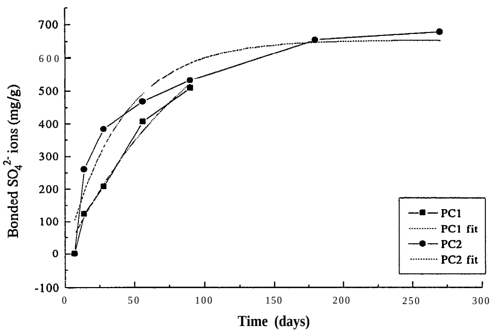

Fig. 5 Experimental and estimated curves for the bonded SO_4^{2-} ions for Portland cements

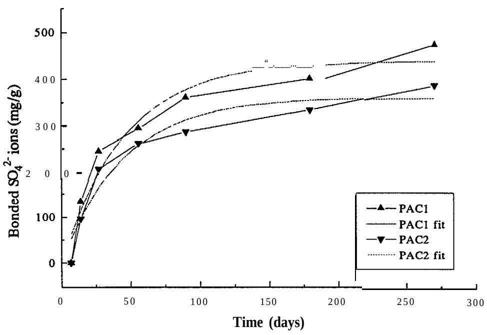

Fig. 6 Experimental and estimated curves for the bonded SO_4^{2-} ions for Portland ash cements

Figs 5 and 6 presented bonded SO_4^{2-} content. to concrete testing samples from the aggressive ammonium-sulphate solution. Curves PC1 fit, PC2 fit, PAC1 fit and PAC2 fit presented estimated curves from Equation /5/ for the bonded SO_4^{2-} content.

Incorporation of sulphates from solution was rather faster to Portland cement PC2 till 90 days. After that time, testing samples from Portland cement PC1 cracked down due to ettringite formation, but the testing samples from Portland cement PC2 lasted for 270 days of examination. Incorporation of sulphates to Portland ash cements were much slower due to protective layer from hydration products formed in such kind of cements.

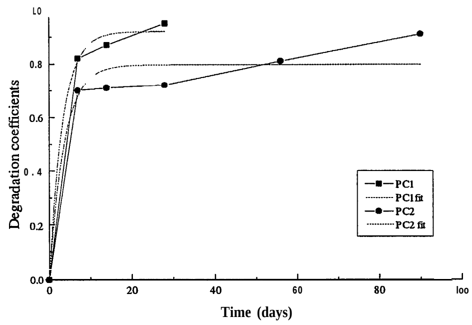

Fig. 7 Experimental and estimated curves for degradation coefficients for Portland cements

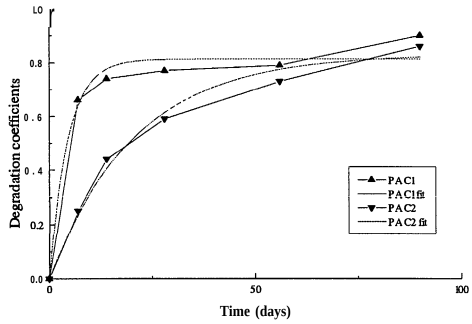

Fig. 8 Experimental and estimated curves for degradation coefficients for Portland ash cements

Figs 7 and 8 presented degradation coefficients of concrete testing samples exposed to the aggressive ammonium-sulphate solution. Curves PC1 fit, PC2 fit, PAC1 fit and PAC2 fit presented estimated curves from Equation /5/ for the degradation coefficients.

From the diagrams, it can be clearly seen that cements with the addition of 30% of ash, show convincingly best characteristics in the used aggressive solution. The increase of corrosion degradation in the very begining for all the cements is a normal phenomenon, because the creation of expansive compounds closes the pores and makes cement paste impervious to aggressive ions. However, further increase in the volume within the paste very quickly results in cracking.

As it could be seen from the Figs 3 to 8, sequence of the got results with the Matsufuji-Koyama model for the cements with the ash addition is much better than for the Portland cements. This means that, in the essence, ash in cements was forming protective layer thus slowering corrosion process and increasing durability. Portland cements, but, showed, depending on the C_3A content, either alignment type or multiplication type of degradation after initial period of forming the protective corrosion process products layer. This layer obviously became negligible due to the NH,‘” ions action thus opening new pores and accelerating corrosion process again.

4 Conclusions

The results of testing the impact by aggressive sulphate environment, that is, the degradation of the selected cements to these impacts, allow for the formulating of certain conclusions:

1. Regarding the resistance of cements to the impact by the environment with sulphate composition, it can be concluded that the lower degradation was shown by cement with a lower content of tricalciumaluminate in clinker PC2 and especially by cements with the addition of ash.

2. Sequence with the Matsufuji-Koyama model for the convergence type of degradation was very good for the cements with the ash addition, but, for the Portland cements, depending on the C_3A content, it was rather alignment or multiplication type.

5 References

1. Biczok, I. (1972) *Concrete Corrosion, Concrete Protection,* Eight Edition, Budapest.
2. Mehta, P.K. (1983) Mechanism of Sulfate Attack on Portland Cement Concrete - Another Look. *Cement and Concrete Research,* Vol. 13, pp. 39-51.
3. Moskvin, V.M., Ivanov, F.M., Alekseev, S.V., Guzeev, E.A. (1980) *Korozija betona i železobetona,* Moskva.
4. Matsufuji, Y., Koyama, T., Harada, S. (1996) Service life predictive method of building materials. *Proc. of "Durability of Building Materials and Components 7",* Vol. 1, E&FN Spon, London, pp. 45-53.
5. Koch,A., Steinegger,H. (1960) Ein Schnellprufverfahren fur Zement anf ihr Verhalten bei Sulfatangriff (A Rapid Test Method for Cement Behaviour Under Sulphate Attack). *Zement-Kalk-Gips,* Vo1.7, pp.3 17-24.
6. Miletić, S., Ilić, M., Ranogajec, J., Djuric, M. (1996) Sulphate Corrosion of Portland Cement and Portland Cement Mixed With Fly Ash and Slag as a Function of its Composition. *Proc. of XVI Symposuim on Nordic Concrete Research,* Helsinki, pp. 339-40
7. MiletiC,S., Ilić,M., Ranogajec,J., Djurić,M. (1997) Behaviour of Hardened Portland Cement and Portland Fly Ash Cement in Ammonium-Sulphate Solution. *Zement-Kalk-Gips - International* (in print).
8. Miletić,S., Ilić,M. (1997) Effect of Ammonium-Sulphate Corrosion on the Strength of Concrete. *Proc.* of *the 10th ICCC,* Vol. 4, 4iv023, Göteborg, 8 pp.
9. Miletić,S., Ilić,M., Ranogajec,J., Marinković-Nedučin,R., Djurić,M. (1997) Ammonium - Sulphate Corrosion in Portland Cement and Portland Ash Cement Concrete. *Proc. of the EUROCORR '97,The European Corrosion Congress,* Trondheim, Vol. I, pp 573-578.
10. Dučić, V., Miletić, S. (1987) Sulphate Corrosion Resistance of Blended Cement Mortars. *Durability of Building Materials,* 4, Elsevier Science Publishers, 13 pp.

Quantitative Measurement and Estimation of Driving Rain on a Building Facade

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Abstract

One of the most serious threats to the envelope of a building is represented by driving rain; when the wall surface is made of porous material part of the rain may be absorbed and part may penetrate into cracks and joints and even cause dampness indoors. Absorption of water ruins roofs and damages walls at the onset of frosts; the moisture inside the building freezes, causing wall deterioration. Moisture in a construction or on the surface may also cause deterioration by salt decomposition, corrosion of concrete reinforcement, mould and rot, chemical conversion, biological attack and corrosion of panel walls. A sustainable construction, therefore, often requires knowledge about the moisture level and moisture variation in the structure. The project described in the paper focuses on predicting, as accurately as possible, the micro climate of outdoor building surfaces, i.e. the temperatures and moisture conditions to be used in determination of durability. The micro climate depends on both the parameters of the structure such as size, shape, type of material etc., and the meteorological loads. This paper describes a set-up for measuring the micro climate primarily focused on wind-driven rain onto a vertical building surface. The *in-situ* measurements were taken at the Fisebäck field station in Sweden. The position of the driving rain collectors were estimated using a CFD-modelling of wind induced surface pressure. Future work within the project will develop a simulation model for quantitative estimation of driving rain onto a building facade. The model is to be used to predict the surface moisture deterioration of the building envelope. The model uses meteorological data, and takes into account the location and the geometry of the construction. The amount of wind-driven rain onto the building surfaces will be described by considering the construction design, variations of wind direction, wind speed and precipitation, seasonal and daily changes.

Keywords: climatological measurement, driving rain, micro climate, simulation of wind, wind around a building

1 Introduction to micro climate - durability

The study presented here is a part of a project called *Description of the micro climate for estimating durability and lifetime: Building components exposed to natural outdoor climate.* The aim of this project is to predict, as accurately as possible, the micro climate of outer surfaces, i.e. the temperatures and moisture conditions to be used in determination of durability.

Variation in the ambient air temperatures cause the properties of the building materials and building construction to vary. The surface temperature depends on ambient temperatures, radiation exchange with the surrounding surfaces and material properties. Variation of the air temperature can give, freezing/thawing of the material (especially dangerous for porous material and surface finish), movements and cracks, and changes in material properties.

Many severe durability problems in buildings are related to moisture. A sustainable construction, therefore, often requires knowledge about the moisture level and moisture variation in the structure. This demands knowledge of material properties, regard to critical moisture levels and to moisture transport properties, and the ambient climate. Moisture reaches the building surface as precipitation, driving rain, air humidity and condensation. One of the most serious threats to the building envelope is represented by driving rain; when the building facade is made of porous material, part of the rain may be absorbed and part may penetrate into cracks and joints and even cause dampness indoors. Absorption of water ruins roofs and damages walls at the onset of frosts; the moisture inside the building components freeze, causing wall deterioration. Moisture in a construction or on the surface may also cause deterioration by salt decomposition, corrosion of concrete reinforcement, mould and rot, chemical conversion, biological attack and corrosion of panel walls.

An estimate of the micro climate at the facade surface must be based on a transformation of meteorological data obtained from a nearby weather station. However, in the present paper, a number of restrictions are made because of the fact that only natural outdoor climate is to be considered. These are: no construction in contact with soil or off-shore is dealt with; no salts or other airborne particles and pollutants are to be taken into account. This paper thus proposes a set-up for measuring the micro climate, primarily focused on wind-driven rain onto a vertical building surface. The *in-situ* measurements are taken at the Fisebäcks field station, Sweden. The position of the driving rain collectors are estimated by the help of a CFD-modelling of wind induced surface pressure.

2 The serious threat of driving rain

Driving rain, or wind-driven rain, is the horizontal component of precipitation reaching a fictitious (free driving rain) or a real vertical surface. The wetting pattern of the wall surface due to wind-driven rain depends amongst other factors on wind velocity, wind direction and type of rain (e.g. size and shape of droplets). The interaction between climatic parameters such as wind, rain and temperature, are of importance for determining the micro climate in proximity to the wall. When obtaining climatic information for building sites it is important to note the distance from the coast, the influence of adjacent urban buildings and specific structures, as well as of the landscape in the immediate vicinity of building site. As well, the geometry and orientation of the building surface affect the amount of wind-driven rain deposited on it. An example from the British Standard Code of Practice [1] showing the wetting pattern on a two-storey gable due to driving rain is provided in Figure 1.

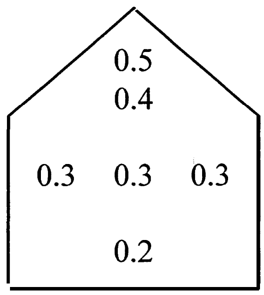


Figure 1 Wall factor for correlation of the driving rain wall indices on a two storey gable due to free driving rain [1]. The greater the wall factor, the more wind-driven rain reach the facade.

3 Review of driving rain on building facade

Driving rain is not systematically measured at meteorological stations. Since only a few locations in some countries conduct experimental measurements, the precipitated amount of driving rain is typically determined by calculation. A review of the physics and properties of driving rain and the means to measure it is offered by Lyberg [2] and van Mook [3]. In reference [2] it is mentioned that Holmgren was the first one to design a driving rain gauge to be installed on the wall in 1937 and that Hoppestad (1955) was the first person for initiate the idea of driving rain index, that in part depended on the relationship between rate of rainfall, drop size and terminal velocity. The rate of water deposition on vertical walls can be calculated according to a method provided by Lacy in [4]. Lacy developed (1965) the basic criteria for using empirical relationships between rainfall rate and drop size distribution according to work by Laws and Paterson [5]. Thereafter, Best found the relationship between the rain dropsize and terminal velocity [6], which when combined with pevious work gives:

$$r_v = \frac{2}{9} \cdot V \cdot r_h^{8/9} \tag{1}$$

where, r_v (l/m^{2}h) is the rate of driving rain on a vertical surface, r_h (mm/h) is the rainfall rate on a horizontal surface and V (m/s) is the wind speed against the wall. Several modifications of driving rain index have been suggested. Prior [7] proposed the sum of driving rain over an azimuth sector of 180°:

$$r_v = \sum r_h \cdot v \cdot \cos\theta \qquad (2)$$

where r_h is the hourly amount of precipitation on a horizontal surface and v (m/s) is mean hourly wind speed for the same hour and θ is the angle between the mean hourly wind direction and the normal with respect to the wall under consideration. Maps provided in references [1] and [8] are based on those expressions, i.e. the annual index and the spell index. The amounts of rain that would impact on a real wall must be multiplied by factors for topography, terrain roughness, obstruction and sometimes the wind. In [1] and [8] the driving rain intensity on an unobstructed fictitious vertical surface is given by the annual index and the spell index above, no wind factor is used.

Investigations of wetting patterns for various wind speeds around building, raindrop trajectory and rain drop size distribution employing CFD-models (Computional Fluid Dynamics) have been performed by Choi [9]. Choi developed a local effect factor LEF(r) and a overall local effect (LIF) for each zone of the facade according to different wind speed conditions and rain drop size distributions based on the following relationships:

$$\mathrm{LER}(r) = \frac{\text{wind driven rain intensity of radius } r \text{ raindrop}}{\text{unobstructed rainfall intensity of radius } r \text{ raindrop}} \qquad (3)$$

$$\mathrm{LIF} = \frac{\text{wind driven rain intensity on building face}}{\text{unobstructed rainfall intensity}} = \int \mathrm{LEF}(r) f(r) dr \qquad (4)$$

where *f(r)* is the probability distribution of water in the air with drops of radius r to $r+\delta r$. The CFD model is still under development and needs further evaluation against measured data; at present time it is limited to simple buildings located in simple landscapes; as which it is only practical as a research tool. It will be some time before it can be used by designers to carry out practical evaluations of the driving rain impact on buildings.

4 Planned measurement of driving rain

The *in-situ* measurements were undertaken at Chalmers field station situated at Fiskeback, Göteborg , on the west coast of Sweden. Macro climate is obtained from three different weather stations of Swedish Meteorological and Hydrological Institute (SMHI) near the field station namely, in; Save, Göteborg and Trubaduren. A reference station for measuring the meso climate near the field station is an important part of the analysis required for transforming the macro climate to micro climate. The instruments measuring the wind speed and wind direction are placed in a 10 metres high meteorological tower. The meteorological tower itself is placed on top of the field station roof.

The micro climate at the facade is recorded with instruments directly applied to the surface being considered.

4.1 Desired climatological parameters

The air pressure is obtained only as a macro climatic value at a nearby meteorological station. The most interesting climatological parameters for describing the micro climate are: air temperature, total net radiation (between the wall being investigated and its surroundings), and wind-driven rain onto a vertical building surface. At the reference station the following meteorological loads are to be measured as meso climate; wind speed and wind direction, air temperature, air humidity, global radiation, total net radiation (between the sky and the ground) for estimating the stability class of the atmospheric boundary layer, and horizontal precipitation.

4.2 Measurement equipment

Meso climate at the field station are registered by a Young model 05103 wind monitor for measuring wind speed and wind direction, a Campbell Scientific 107 thermistor probe in a radiation and precipitation shield, a Young model 41002 for measuring the air temperature, a Rotronic MP 101 for measuring the air humidity in the same shield as mentioned above, Campbell Scientific model SP1 110 a pyranometer sensor for measuring the global radiation, a REBS model Q-7 net radiometer for measuring the total net radiation for horizontal surfaces, and, a ARG1 00 rain gauge for measuring the horizontal precipitation.

Driving rain onto the wall is measured with three different gauges constructed at the Department of Building Physics, Chalmers:

- a collection plate with a tipping bucket for registration of the amount of driving rain.
- a collection "hole" in the wall with a balance as measuring unit.
- a portable collection plate with a balance as a measuring unit.

The wall being studied is also equipped with a REBS model Q-7 net radiometer for measuring the total net radiation and two Campbell Scientific 107 thermistor probes for control of the air temperature measurements. A Campbell Scientific CR10 was used for measurement and control, and was linked by a fax-modem to Chalmers.

Measurements and calculations included:

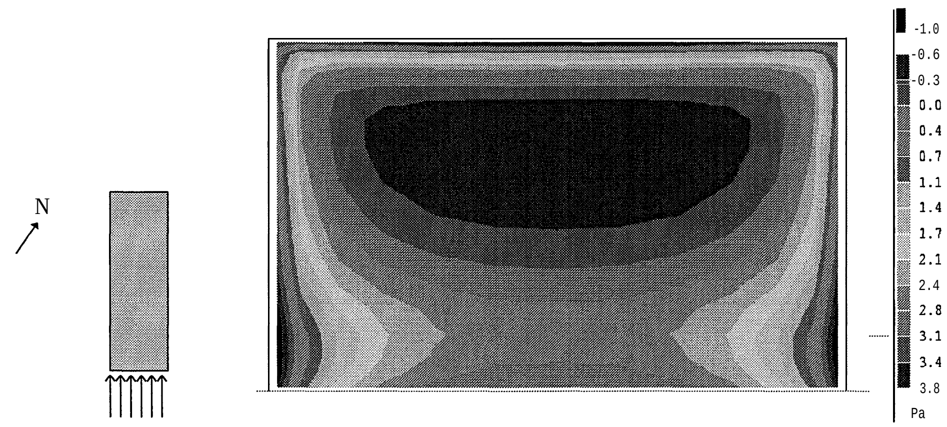
- Ambient temperatures and air humidity; frequency 5 s^{-1}, lo-minutes and 24 hours mean value, calculation of dew point based on 10 minutes average temperature value.
- Wind direction and wind speed: frequency 1 s^{-1}, 1 and 10-minutes and 24 hours mean value, maximal wind gust per hour, standard deviation for 1 and IO-minutes mean value per hour.
- Precipitation and driving rain: 1 and 1 O-minutes mean value , 1, 6, 12 and 24 hours mean value, accumulated volume of precipitation.
- Global radiation and net radiation: frequency 5 s^{-1}, 1 O-minutes mean value, 1, 6, 12 and 24 hours mean value.

5 Wind climate at the test house

Wind flow around the building at the field station was modelled in co-operation with SMHI. A steady-state simulation of the k-ε turbulence model was performed in Phoenics, a CFD-program. The following assumptions were used due to homogeneous horizontal surroundings and stratification of the atmosphere:

- the atmospheric boundary layer has neutral thermal stratification;
- the up stream wind has a power law wind velocity profile with a terrain roughness exponent of 0.14;
- friction against the building surfaces is taken into account;
- the air temperature is about 20 °C.

The building has the form of a rectangular box 22.1 meters long, 7.2 meters wide, and 4.3 meters high and has a flat roof. The orientation of the south-east gable is 150°. Distance from the house to the sea is about 50 metres. One output of the CFD-simulations gives the wind induced surface pressure for the four walls and the roof. The calculated distribution of the wind pressure (Pa) onto the south-east gable is shown in Figure 2. This illustrates the effects of the wind (3 m/s) blowing straight at the gable. This wind direction is one of the most frequent ones according to [10]. The south-east wall surface has one of the orientations with largest amounts of collected driving rain for the location Göteborg, see [11].



a) b)

Figure 2 a) The wind direction due to orientation and geometry of the building. b) The distribution of the wind pressure (Pa) at the south-east wall surface, which illustrates the effects of the wind with the speed 3 m/s.

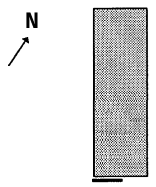
6 Position of the driving rain gauges

From field measurements it is known that the intensity of driving rain is highest close to the edges, i.e. corners and regions close to the roof. The air flow approaching the building is forced to change direction in order to flow around it. The wind velocity and direction will increase around the considered edges. The drag force representing the interaction between the air and the raindrops are not sufficiently strong to carry the rain drop around the building. At the edges, where the acceleration of the air flow field is highest, a great number of rain drops are falling out of the air stream, and will hit the wall surface. Changes in the air velocity field at the facing wall will result in steep air pressure gradients. High pressure gradients can therefore be used as an indicator for areas of the wall that are likely to represent high driving rain intensities. In Figure 2 the area with a higher pressure gradient than 0.6 Pa/m becomes the target region for driving rain collectors. The number and types of driving rain gauges on the building surfaces is presented in Table 1.

Types of driving rain gauges	south-east wall	south-west wall
a tipping bucket	6	2
a hole in the wall	**1**	**1**
a plate and balance	**6**	**2**

Table 1 The number and types of driving rain gauges on the building surfaces.

The position of the collectors on the south-east wall are shown in Figure 3. To obtain reference levels the collectors on the south-west wall are placed in an area where the estimated pressure gradients are small, i.e. at the centre and upper part of the wall.



a)

b)

Figure 3 a) The position of the collectors due to orientation of the building.
b) The position of the collectors on the south-east gable, Fiskeback.

7 Discussion and conclusions

Result from calculation performed by Choi [9] of raindrop trajectory from the equation of motion of the fluid particles moving in the wind field shows a similarity with field experiments. In order to simplify the calculation of the wind field, potential flow theory can give reasonable approximation of the air flow field at the windward face, which is the part of interest in these studies. Further simplification can be made by considering a 2-dimensional flow field along the roof and along the corners of the building. Valuable and useful approximate expressions can be developed and used in the determination of the driving rain intensity.

In this project the development of simplified simulation models will use these types of approximations. The future model is to be used to predict the deterioration of the building envelope due to surface moisture. An important part of the model is the transformation of climatological parameters, single or combinations thereof, for building purposes. The model is to take into account meteorological data as well as the location and the geometry of the construction. The amount of wind-driven rain onto the building surfaces are to be described by considering the construction design, variations of wind direction, wind speed and precipitation, on the basis of both seasonal and daily changes. The *in-situ* measurements at the Fiskeback field station will be used to validate this simulation model.

8 Acknowledgements

I would like to express my gratitude to Carl-Eric Hagentoft Prof, Chalmers, and Roger Taesler Dr, SMHI, for their supervision; and to Bengt-Åke Peterson Assoc Prof, Chalmers, Antonio Morais Eng, Chalmers, and Erik Johansson, SMHI, for their support. The project is financial supported by the Swedish Council for Building Research and by stipends from Åke och Greta Lissheds stiftelse and Adlerbertska forskningsfonden, whom also are acknowledged.

9 References

1. BSI. (1992) *British Standard Code of practice for Assessing the exposure of walls to wind driven rain, BS* 8104, *1992*, British Standard Institution.
2. Lyberg, *M.* (1979) *Review of Micro- and Buildingphysical Properties of Driving Rain,* M79: 13E, SIB.
3. van Mook, F. *(1996) A plan for the measurement of driving rain on a building, 3* rd BEATRICE Euroconference, Nantes, 4-6 Sep, 1996.
4. Lacy, R. *(1965) Driving rain maps and the onslaught of rain on buildings,* RILEM/CIB Symposium on Moisture in Buildings, Helsinki.
5. Laws, J., Paterson, D. (1943) *Relation of raindrop size to intensity,* Amer. Geophys. union Trans, 24. part II. pp 453-460.
6. Best, A. (1950) *The size distribution of raindrops,* Quart J. R. Meteor. Soc., 76, pp 16-36.
7. Prior, M. J. (1985) *Directional driving rain indices for the United Kingdom - computation and mapping.* Background to BSI Draft for Development DD93, BRE.
8. CEN/TC89N Working draft (1996)
9. Choi, E *C. C. (199 1) Numerical simulation of wind driven rain falling onto a 2-D building,* Proc Asian Pac Conf Comp Mech, Cheung, Lee & Leung (eds), ISBN 9054 10029X.
1 O.Harderup, E. (1995) *Klimatdata fir fuktberäkningar,* Report 3025, University of Lund.
11. Taesler, R. (1972) *Klimatdata för Sverige.* ISBN 9 l-540-20 12-3.

From theory into practice. Subarctic ecological building in Östersund.

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The ecological planning and building engineering program at the Mid Sweden University in Östersund is based on a traditional construction engineering program but is permeated with ecological reasonings. Besides the traditional courses the students take courses in ecology, ecological town and country planning, the technology of installations, ecological planning and building, environmental management systems, indoor environment, shape and artistic work which all are courses where the ecological reasoning is the main part. The ecological planning and building engineering program is the only of its kind with a pronounced ecological profile in Sweden.

The ecological building centre in Ås is a practical project work in full scale which is mostly planned, designed and built by the students at the ecological building and planning program and building engineers in co-operation with local enterprises in the branch of building trade. When the project is finished, there will be five different houses and one small village composed of five cottages.

The first house, which will be finished during the spring of 1998 is a two storey apartment and office building. The house is built with ecological and locally produced materials. The ventilation system is based on a principle where the air goes through a small greenroom where it will be preheated and then flows in the rest of the house. The heating system is based on a wood-pellet boiler and solar collectors.

The second house is made of earth and straw clay. The earth walls are stamped in a wooden mould and become almost as hard and durable as concrete. The straw clay wall is also stamped in a wooden mould but not as compact as the earth walls.

Next stage of the development is to build an environmental laboratory, a storage and a recycling workshop, there will also be a permaculture garden in the area.

Keywords: Earth walls, ecological building centre, ecological planning and building engineering, green room, sedum plants, straw clay walls,

Introduction

At the Mid Sweden University in Östersund, which is a town in the middle of Sweden, there is a programme that educates Ecological planning and building engineers. The programme was founded in 1994 and it is the only one of its kind in Sweden, since it started two classes has graduated. The Ecological planning and building programme has a close co-operation with the Ecological building centre in Ås. Ås is located about 10 km from Östersund. This paper will give you a short introduction about the Ecological planning and building programme and the Ecological building centre in Ås.

1 The Ecological planning and building engineering programme

The ecological planning and building engineering programme at the Mid Sweden University in Östersund is based on a traditional construction engineering programme but is permeated with ecological reasoning. Besides the traditional courses such as construction, building physic, mathematics, building production and Computer Aided Design, the student also take courses which are concentrated on ecology. Those courses are:

- Ecology which is the first course in the programme, there the students learn how the ecological balance in the nature works and how to follow the law of nature.
- Ecological town and country planning. The students learn how the sustainable community of the future will be reached and developed.
- The technology of installation is a course where the students learn about the interplay between installation systems of the house and to economize the use of energy. They also learn how to take care of and use the renewable energy sources like solar energy, wind power, heat exchanger and so on.
- Ecological building and planning is a course based on real projects where the students use knowledge acquired in previous courses. The project can for example be composed of planning the living space in a house, the calculation of the framework, heating and ventilation system and find system that are suitable for the project. All through the project the students maintain contact with the customers who express their wishes and demands.
- Shape and artistic work is a course where the students are given an opportunity to develop their creative and artistic skills in modeling, painting and construction of models.
- Environmental management systems is a course where the students deepen their knowledge about environmental management systems like EMAS and IS0 14 000.
- Indoor environment. The students learn how people are affected healthwise by the indoor environment. They read about allergies and other diseases caused by a unhealthy indoor environment.
- Ecological building technique is a course that takes place each summer at the ecological building centre in Ås. The students will there have the possibility to get the six weeks long practice that is required. This is a course that gives the students a good opportunity to transform theoretical ideas into practically useful solutions.

The ecological thread permeates also the traditional courses. The students learn about environmental management systems IS0 14 000 and EMAS (Eco Management and Audit Scheme) and also about quality management systems like IS0 9 000.
By working in groups with real projects the students learn how to solve problems, find solutions and work together with other people.

This is the only construction engineering programme where the ecological approach follows the student throughout the whole education programme, from the start to the exam.

2 The ecological building centre in Ås

The building centre is an ecological and practical project work in full scale. It is mostly planned, designed and built by the students at the programme of ecological planning and building engineering in co-operation with local enterprises in the branch of building trade.

Plan of development 1995 - 2010.

Building

1. Apartment and offices
   1995-97 96,5 sq. m.
2. Experimental earthhouse
   1995-97 26,2 sq. m.
3. Environmental laboratory and experimental workshop
   1998-00 380 sq. m.
4. Storage, woodshed and underground storehouse
   1999-2001 total 80 sq. m.
5. Recycling workshop
   2001-03 120 sq. m.
6. Researchers cottage with five small houses
   2003-10, 5x30 150 sq. m.
7. Permaculture garden
   2000-2010 3000 sq. m.

All the buildings will be formed as independent research objects, since they will be constructed from different materials, built with different methods and techniques and the buildings will be heated, ventilated, etc. with different systems. Carefully measured and analysed in comparison to each other.

The exploitation of the ecological building centre depends on the sponsorship that the foundation of the ecological building centre receives from enterprises in the branch of building trade and private donators.

In the choice of construction-methods there has been a strong desire to make it possible to dismount the construction without destroying individual parts or materials.

The choice of materials for the houses in the ecological building centre are based on following criteria:

- Local presence = minimized transportation
- Locally produced = minimized transportation

- Low energy-demanding manufacturing processes
- Non pollution - non toxic materials
- No vapour barriers
- Recyclable materials

The choice of systems for the houses in the ecological building centre are based on following criteria:
- Lowest possible technical level
- High efficiency
- Easy operated
- Visible processes
- Understandable to non-technicians
- Recycling flows

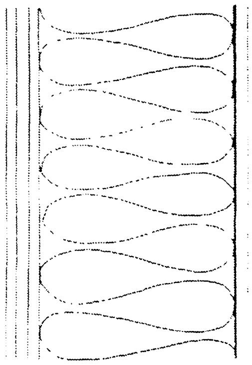
2.1 Building no 1. The two storey apartment- and office building.

Foundation-walls: The foundation-walls are bricked with LECA-blocks (cement and expanded clay-pellets), lime-mortar and reinforced concrete-footings.

The porches on both ends (east and west) of the building are constructed with post foundation down below frost line.

Bottom system of joists: On site prefabricated modules of reinforced concrete slab floor sheets, 120 mm in thickness. Top surface is covered with slate from local quarries and set in lime-mortar. There is no insulation between the groundfloor and the foundation space.

Outer walls: A double wooden framework, where the outer is carrying the load from the trusses and the truss-joist. The inner is carrying the load from the middle system of wooden joists. (Fig. 1)



23 mm wooden panels
23 mm ventilated space
12 mm wood-fibre sheet
360 mm cellulose insulation (EKOFIBER)
wood-fibre textile
16 mm wooden panels / 12 mm gypsom wallboard

Fig. 1

Boiler-room 1st floor and bathroom 2nd floor: The surrounding walls are built as a bricktower, divided in to floors by a reinforced concrete slab floor in order to lead the warmth from the boiler-room up into the bathroom without installing heat piping into the floor but still functioning as a radiant heat floor system. The bricks in the wall are known to absorb and transport damp from the moist bathroom into the surrounding areas, increasing the humidity of the indoor air, which during the winter is too dry to be pleasant for the inhabitants.

Gable outer-roof and hip-roofs over porches: Waterproof, asphalt saturated roofing felt covered with lightweight carpets of living sedum plants. During the spring, summer and autumn it's blooming in white, yellow, pink and red colours against a green bottom.

Solar-collectors: They are a part of the heating system and produce domestic hot water during late spring, summer and autumn. A circulation pump is operated by electricity from solar-voltaic cells integrated on the roof.

Heating system: The base is a wood-pellet fired boiler, with a hot water storage tank also coupled up to the solar collectors. The warmth is distributed by a system of hot water-radiators. There are secondary fireplaces in both kitchen and living room.

Ventilation system: Natural ventilation by taking advantage of the strong negative air pressure inside the house during winter conditions. Fresh-air-inlet through the permeable insulation of the greenhouse-ceiling The incoming air will hereby be both filtrated and prewarmed by absorbing the warmth which is constantly leaking out through roof-construction when colder outside.

During the summer, ventilation air is lead into the house from the shaded and more chilly northside of the building through wide, underground concrete pipes to inlets in the south facing greenhouse where the need of cooling is the biggest. By letting the air flow through underground pipes, the temperature of the air will be considerable lowered. Required airflow is created either by opening windows or by use of a chimney top-mounted fan.(fig 2)

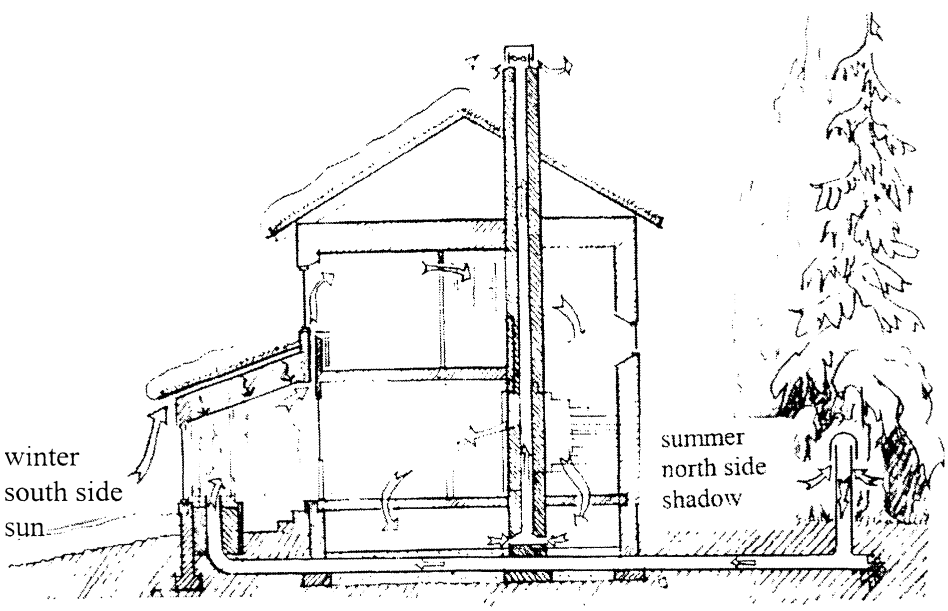


Fig. 2 Ventilation system for house no. 1

Glass partition: A glass partition is arranged between green room and living room to steer the prewarmed air entering the green room through channels and inlets further on to the upper floor bedrooms. By the strong negative air pressure the flow of air is then drawn down stairs and through air slots in the bottom system of joists further down into the ground space, where it warms the concrete slab floor before entering the exit openings of the chimney pot. Again a heat exchanger without moveable parts.

Windows: Nicely profiled wooden framed doubleglass windows with an metallic coated inside to prevent leakage of longwaved heat radiation from in to outside.

Toilet system: Low flushing urine-separating toilet. Quickly drying for later composting together with changed out greywater peat-filters and used as soil improvement in the garden.

Grey water system: Water from shower, doing the dishes and washing is collected and lead to a simple, on site manufactured peat-filter in the same cabinet as above, where also the urine UV-filter is placed. After filter treatment the greywater is mixed with the treated urine. The nutrient solution flows through pipes under the bottom system of joists into the cultivation beds of the green room. The loop of waste becoming valuable nutrients and irrigation water for growing vegetables to put on the table is closed within the outerwalls of the house.

Electrical system: Enclosed wire in conduit system are installed in order to minimize discomforts from electromagnetical fields.

Surface materials: There are used slate and limestone, solid wood from pine and spruce, gypsom wallboard and woodfibre wallboard. When available they are bought from local enterprises.

Indoor: Depending on function, linseed oil, a mix of linseed oil, turpentine and wooden-tar, slime paint, honey beeswax transparent paint, egg-linseed-oil tempera and limewash colours.

2.2 Building no 2. Experimental earhthouse

The area of the earthhouse is 26,2 sq. meters.

The foundation walls are bricked with LECA-blocks (cement and expanded claypellets). The floor is made of LECA pellets and a claymixture of clay, sand, chopped straw and water. There are two layers of this clay mixture and in the last one it is possible to add linseedoil and colourpigment to make the floor more resistant to wear, and to give it a nice shade.

The earthwalls, Piséwalls, are built directly on the foundation walls with a asphalt saturated roofing felt between. To the walls are used a wooden mould which you fill with earth and stamp compact with different tools. (Fig 3)

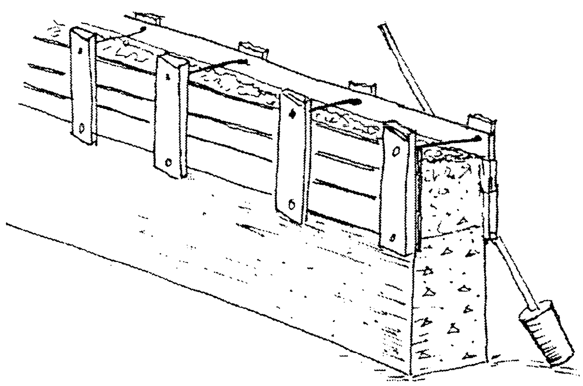


Fig.3 The construction of the mould where you stamp the pisé wall.

One of the walls are made of straw clay. A wooden framework are the base and a wooden mould (like the one used to the pisé wails) are nailed to the framework. (Fig 4)

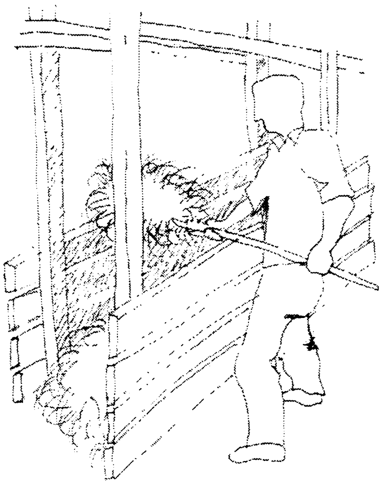


Fig. 4 The straw clay is filled in the mould.

The mould is filled with straw mixed with clay soaked in water. The straw clay is stamped compact but in the middle it is left unstamped to increase the insulation property. (Fig 5)

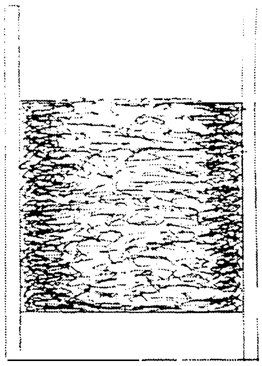


Fig.5 The straw clay stamped in its mould.

There are a clay plaster on the walls. The first plaster mixture for the straw clay wall is a mixture of clay, sand, sawdust, chopped straw, manure and water. In the second layer the manure is excluded and the part of sawdust and chopped straw is increased.

The plaster mixture for the pisé walls is a mixture of clay, sand, sawdust, fur or chopped straw and water. In the second layer the sawdust is excluded, the part of sand is increased, EKOFIBER and manure are added.

All these plaster-mixtures are easy to do and easy to work with, the plaster is spread onto the straw clay wall by the hands and onto the pisé wall with a trowel.

The windows and the door are reused from houses nearby.

The ceiling is made of “vicklingar”. It is straw clay rolled around a woodenstick. A layer of a plaster mixture made of clay, sand, chopped straw and water are spread on the “vicklingar” to give them a nice surface. These “vicklingar” give the ceiling a billowing and beautiful character. (Fig 6)

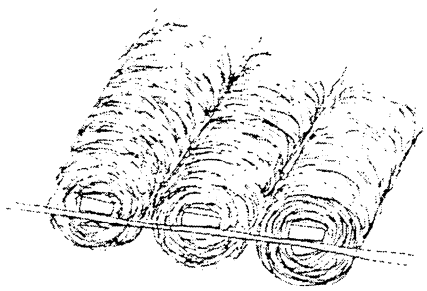


Fig. 6 “Vicklingar”

On the roof there is a waterproof asphalt saturated roofing felt covered with light weight carpets of living sedum plants. The plants are blooming in white, yellow, pink and red colours against a green bottom and give the house a very special character.

Climatic variability and climate change - implications for design and construction

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This paper outlines the current state of research on the consequences for buildings of climatic variability and climate change. It has been prepared based on information provided by members of CIB Task Group 13 and it is hoped that it will provide a discussion document for future research in this increasingly important area.

It is accepted that both local and global climates have varied throughout history. Long-term variations have resulted in the Ice-ages that have so shaped the present landscape whilst shorter term variations lead to the settlement of new areas - for example the occupation of Greenland by Norse settlers at the end of the last millennium. At the end of this millennium there is a substantial body of scientific evidence that the climate is changing again as a result of the emission of 'greenhouse' gases which are leading to 'global warming'. There are potentially many serious consequences of changes in the global climate, for example the flooding of low lying areas as the sea-levels rise and the loss of ecological habitats.

The aim of CIB Task Group 13 is to begin to evaluate the sensitivity and vulnerability of the built environment to these climatic changes. The paper includes a brief introduction to climate change and then highlights some current areas that international research is highlighting as important. The paper then considers some the potential effects of climate change on the durability of building components (and prediction of service) and so complements the work of CIB W80/RILEM 140-PSL.

The final part of the paper looks towards the future potential and possible directions of long term research that will help to clarify the potential impacts and to identify where changes are required in the codes and standards that underpin the design of buildings.

1 Introduction

From the earliest times until the 20th century the design and construction of buildings has largely been controlled by three inter-related factors - the availability of materials, the ability to extract and work these materials, and the climate.

Any examination of the traditional architecture of a region or city will illustrate this idea - whether it's the use of extensive use of timber in Scandinavia, the brick buildings of the Netherlands or the marble of northern Italy. The architecture also varies with time in response to the changes in technology that allowed stone to be cut or larger timbers to be sawn. Technological developments also lead to the ability to transport materials over greater distances either because of their desirable qualities but more often because of the prestige associated with their ownership.

It was also the development of technology that seemed to signal a reduced importance for the final factor - climate - as people began to control of the environment within their buildings. Man is now able to go far beyond the simple idea of providing heat in the cold and fresh air in the summer and is able to produce 'day light' when and where it is required and to control temperature and humidity at will or in response to short-term external climatic changes. It is this area that the newly formed CIB Task Group 21(Climatic Data for Building Services) is concerned with. However, the effect of climate goes far beyond heat and light and it is necessary to relearn old skills and adapt them for new constructions so that they are able to withstand high winds, floods and droughts. Increasing importance is also being given to the need to design for durability and to predict the service life of materials, components, units and structures which is the research area of CIB Working Commission W80 (Prediction of Service Life of Building Materials and Components).

In recent years it has become clear that there may be one more climatic parameter that must be considered and that is the longer term fluctuations in climate included the long-term trends which are generally grouped together as the "greenhouse effect" and it is this area that this contribution deals with.

2 Background

The accumulation of "heat trapping" gases was first suggested by the British scientist John Tyndall in 1863, he was also the first to use the term 'greenhouse effect'. In the late 19th century Svante Arrhenius and P.C. Chamberlain considered the possibility of global warming occurring as a result of the emission of carbon dioxide from fossil fuels. In the 1940s research showed that the mean global temperature had increased by 0.25°C between 1870 and 1940 and it was suggested that the United States 'dust bowls' of the preceding decade were a result of the anthropogenic 'greenhouse effect'. Measurements made in the following 30 years (1940 -70) [1] showed the world to be cooling and by 1970 it was back to a level similar to that recorded in 1880. However, in the 1970s studies of concentrations of CO_2 and observed rises in global temperature renewed interest in the 'greenhouse effect'. By the late 1980s there were indications that the effect was real - global temperatures had risen between 0.5°C and 0.7°C since 1880 [1] with the six warmest years on record all occurring in the 1980s. The Intergovernmental Panel on

Climate Change (IPCC) provided 'official' confirmation of this by stating that the global warming of the last 100 years is unlikely to be due entirely to natural causes and that the balance of evidence suggests there is a discernible human influence on the global climate [2].

The spate of record breaking global temperatures in the last two decades has resulted in research into both past climates and potential future ones. These studies have included studies of potential impacts on most aspects of the natural environment and on many aspects of social and financial aspects - population pressures, insurance claims and the buildings. Details of the predicted changes in climate have been reported in many articles and reports and here it will suffice to say that global temperatures are predicted to rise but with regional climates of the world responding differently [2].

Studies of past climates have shown that there have been many fluctuations. Some last only a short time, for example the long dry spell in Iberia between 1993 and 1995, and design and construction cannot respond to these. If a response is made then it may take the form of the provision of additional building services. Other fluctuations have lasted hundreds of years, for example the 'Little Ice Ages' of the medieval period in northern and western Europe and on this sort of time scale the construction of buildings were able, and hopefully would still be able, to adapt to the changing environment.

In the present world it is possible to look for responses to different climates by observing building with similar functions in different climates, for example how do high-rise office blocks vary between cold and hot climates or between wet and arid climates? The adaptations can be wide ranging and include both changes in design and in the selection of materials. However, in some buildings we see designs and materials take unchanged from one region to another with consequent failures of fabric or structure.

In looking to the future there is a need to examine the possible climatic changes being predicted by the Global Circulation Models (GCMs) [2] and their potential for effecting buildings and building materials both by increasing the failure of existing structures or by a requirement for changes in building design, standards or regulations.

3 International research

Research on climate change and variability is long term - both in the sense that we are looking several decades into the future and because the range of information required cannot be gathered quickly. However, because the changes in climate are on a similar timescale researchers are in a position to carry the research and implement the results to the mutual benefit of the population.

In order to address the impact of climate change national and international research is beginning to address a range of questions including:

- the potential environmental and economic impacts of climate change on building performance, particularly the existing stock of buildings;

- the need to alter and adapt the design of future buildings in response to temporary and permanent changes in climate;

- possible changes needed to climatic design values and to design methods involving climatic actions.

One starting point has been to examine traditional responses to climates - taking the past and the present as a basis for predicting the future. This has included studies on the potential effects of climate change on the durability of building components and prediction of service life. In the long term, this work needs to be fed to international standards (CEN or ISO) so that the performance requirements can be realistic for different climates and for the whole life of the building.

One way of examining responses of building and materials to future climates is to review information on the sensitivity of materials to the present climate. However, this shows that there is a substantial lack of understanding and information. Some of the problems stem from the ever present problem of linking accelerated laboratory testing to performance under atmospheric conditions. Consequently, it is impossible to quantify the impact of a temperature rise of a few degrees, a 10% increase in UV-dose, a 10% change in driving rain, etc. It is said that the climate of a city such as Amsterdam will change into the present climate of Paris but at present it would be difficult to indicate differences in the durability of materials on these two cities or to demonstrate that the architect is responding to the slightly different climates rather than to national tastes or the available material.

Evidence suggests that the main impact may be seen in the energy demand of buildings as it is well established that the thermal performance of a building is sensitive to even a 2°C change in climate. Research in the UK [3] has estimated that the impact of climate change on ventilation and air-conditioning systems could be:

- an increase in peak electricity cooling load of 8% for 2°C
- a reduced efficiency of air-conditioning systems of 5% for 2°C
- a need to alter the design of passively cooled buildings

It is important to remember that all of these potential increases in energy consumption must be seen again a background where the requirements are to reduce CO_2 emissions in the next decade. Research in Russia [4,5] has demonstrated that a drop in temperature - as is predicted for some regions - can also be very demanding in terms of the extra energy required. For examples data [6] shows that a although a 2°C rise in temperature can reduce heat loss from a domestic building by 10-12%, a 2°C fall in temperature can increase heat loss by 20-22%.

The need for increased cooling may seem a low priority in the temperate climates of northern Europe but in areas where the temperature is more extreme the need can become a matter of life and death. Research in the United States showed that a short but intense heat wave in July 1995 caused 525 deaths in Chicago [7]. An assessment of causes for the heat-wave related deaths attributed some of the fatalities to the inability of many people to properly ventilate their residences due to fear of crime and to lack of resources for fans or air conditioning.

The other area where there has been widespread research is the effect of increases in extreme wind events. There has been extensive research on this subject in the Netherlands [8, 9] which covered both the direct effect of increased wind speeds and the incidence of tropical storms but also the indirect effects such as the impact on insurance for buildings which also effects the availability of funding for new developments.

In the UK there was considerable interest in extreme wind events after the 1987 ‘hurricane’. Review produced at the time showed that this event was unusually but not outside the range of the previous 200 years [10]. However, reviews [1 1] have shown that much of the damage occurs when the wind speed is well below the design wind speed and much of the damage is the result of poor workmanship and insufficient maintenance. Research in the UK has also show that buildings can be very susceptible to changes in wind mean wind speed and that a 15% increase would reduce the current return period for normal building design from 1 in 50 years to about 1 in 3 years. This could result in a need a start designing buildings for a return period of 1 in 1000 years to account for a future 15% increase in wind speed [12].

4 Climate change and durability of materials and components

This is an interesting area in relation to long term climate change as the whole research area relies on predicting trends and using these to provide a future perspective on possible design responses. On one hand there are the predicted trends in climate - increase in warm summers or increased rainfall - which is clearly the area in which atmospheric scientists work and which is made available through the Inter-Governmental Panel on Climate Change [2].

On the other hand there are the trends in research that are needed to relate climatic change and variability to construction needs. The effect of climate on construction can be tackled from two directions and both seem to have roles in future research. The first is usually termed ‘top down’ and concentrates on making inventories of failures that occur (or have occurred) in the building stock. Analysis of this type of data can identify the parameters that seem to be associated with failure - for example rain penetration of building fabric - and also indicate how design guidance can be amended to overcome potential problems. Naturally, this type of approach is often closely linked to other research topics, in particular those associated with designing for durability and predicted service life.

The second approach is termed ‘bottom up’ and concentrates on the analysis of mechanisms by which agents (wind, rain, etc.) give rise to failure. At first this approach can seem likely to give more generally applicable results as it is more theoretically based and may well involve modelling of some form. However, experience in other fields, including the climate change modelling, have show that the width and complexity of the models, combined with many parameter uncertainties, can lead to substantial error bars on the final results. The ‘top down’ approach tends to be more empirical and although less widely applicable, may give more meaningful and useful results.

However, it is clear that the eventual goal must be to develop predictive equations or methodologies that allow assessment of the impact of changes in climate on a whole building, for example the wind load on a whole structure, the transport of rain onto the shell of a buildings or the thermal performance of a whole building.

5 Towards the future

The driving force behind much of the future research may well be economic pressure rather than a desire for knowledge. The investment needed to construct new buildings is substantial but the amount needed for repair or remedial works in response to extreme events can be many times greater and the insurance industry is taking a considerable interest in the prediction of climate change. There are also substantial costs associated with inappropriate designs for buildings, ones that do not perform satisfactorily in their present climate. Estimates of repair costs combined with lost productivity from the occupants have shown that during the lifetime of the building these costs can exceed the original construction cost.

It seems clear that we need to be able to optimise our building designs and choice of materials to both the requirements of the occupants and the present and future environment around the building. It is also clear that the optimisation must be an iterative process that includes both the use of the building, the occupants and increasingly the need for sustainable development.

For many hundreds of years mankind has striven to control his environment and to alter the climate of his immediate surrounding. We now believe ourselves in a position to do this but this is no time for complacency and we must continue to study and adapt our buildings to meet the demands of society and the ever changing world around us.

6 Acknowledgements

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7 References

1. Hansen, J. and Lebedeff, S. (1987) Global trends of measured surface air temperature. *Journal of Geophysical Research*, Vol. 92, pp. 13345-13372.
2. *IPCC* (1996) *Climate Change 1995: the science of climate change*, (eds) Houghton, J.T., Meira Filho, L.G., Callender, B.A., Kattenburg, A. and Maskell, K., Cambridge University Press, Cambridge.
3. Willis, S. and Perera, E. (1995) Keeping Control of *Comfort, The CIBSE Journal,* Vol. 17, No.2, pp43
4. Malyavina, E. et al. (1973)
5. Malyavina, E. et al. (1983)
6. Kobysheva, N.V. (pers.comm)
7. Changnon, S.A., Kunkel, K.E. and Reinke, B.C. (1996) Impacts and responses to the 1995 heat wave : a call to action, Bulletin of the American Meteorological Society, 1995, pp1497.
8. Downing, T.E., Olsthoorn, A.A. and Tol, R.S.J. (1996) *Climate Change and Extreme Events - Altered risk, socio-economic impacts and policy responses,* ECU Research Report No. 12, Vrije Universiteit, Amsterdam.
9. Stuurgroep Windtechogie (1994) *Klimaatverandering en Stormen*, Kivi, Netherlands

10. Burt, T. and Coones, P. (1990) Winds of Change? The gale of 25 January 1990, *Geography Review,* May, pp22-29
11. Buller, P.S.J. (1993) *A thirty year survey of gale damage to buildings in the United Kingdom,* Building Research Establishment Report, Watford, UK
12. Blackmore, P. (pers.comm)

More sustainable construction using building systems based on pre-stressed concrete elements

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Abstract
Sustainability should not be analysed only on the level of building products, like for instance floor elements. The whole structure should be considered, including beams, columns, foundations and other elements. Also the layout of the building may be influenced by the set of components available within a system. The layout has an effect upon the use of resources per metre square of floor area. The element method for cost control provides a well established tool for monitoring and controlling the quantity of elements per square metre of floor area. The density per floor area will not only affect the use of resources for the construction of the building, but also for maintenance and renewal. The density of external walls, roofs and floors will have consequences upon the use of energy per square metre floor. The layout of the building can also affect the required land and thus indirectly the use of energy for transport. The most challenging problems in Life Cycle Analysis are, besides the problem of definition of a “functional unit” as discussed above, : the selection of a manageable set of indicators, the definition of system boundaries and the determination of ponderation factors for the different aspects. The text proposes to solve those difficulties by replacing Life Cycle Analysis by Life Cycle Costing. Of course the remaining problem is to determine a socially acceptable price for scarce materials, for energy and land. The main advantage is that via a system of eco-taxes costs can clearly be allocated. A long term scenario for real price evolution creates a transparent situation. This requires however a certain political courage since it will become clear that the preservation of rights of future generations will reduce the real incomes. The eco-tax offers the possibility of income corrections. An other aspect is the functional lifetime of structures. Larger spans will increase the use of materials and energy, but will also facilitate adaptations of a structure in case of changing functional requirements. A longer lifetime involves a reduction of waste and consumption of energy for demolition and recycling.
Keywords : pre-stressed concrete elements, sustainability, system building.

1 Introduction

In Belgium, as in many other countries, several suppliers offer “open building systems” mainly based on pre-stressed floor-, roof- and beam elements for industrial halls, for office buildings, for commercial buildings, etc. Since “building systems” are developed to be produced during several years it becomes worthwhile to analyse their characteristics. In recent years there has been a significant emphasis placed on evaluating the sustainability aspects of these systems.

2 Life Cycle Analysis

In order to make a relevant comparison of the environmental effects between different solutions, a basis for comparison has to be established, called the “functional unit”. One square metre of storey floor can be considered as such a functional unit.

In a recent study [1] three types of floors were compared (see Fig. 1):

1. a pre-fabricated and pre-stressed hollow-core floor;
2. a “shuttering slab floor” composed of a pre-fabricated concrete permanent shuttering on top of which an in-situ concrete layer is applied;
3. a floor completely cast in-situ on a reusable mould.

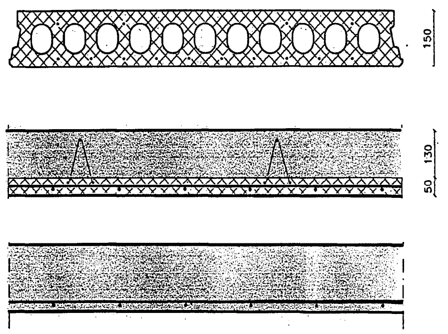


Figure 1 Three floor types

The most striking differences between the three alternatives is (Table 1) the fact that the mass of concrete and steel used per square metre of floor for the “hollow-core floor” is much less than for the other types of floors: only 62% for the concrete and ± 50% for the steel. The values are obtained for a span of 5.4 m and an overload specific for single family housing.

Table 1 : Mass in kg/m² floor

		shuttering slab floor	cast in-situ floor
concrete	263.7	423.0	423 .O
steel	3.2	6.4.	6.1

The second important difference is that for the “cast in-situ floor” propane heating is used to speed up the hardening in order to reuse the shuttering system. Each m² requires 3 litres of propane which should be converted into total energy content (including production and transport of propane).By analysing all the steps in the production cycle one obtains absolute values for the environmental effects; they can be grouped under the following headings (Table 2):

- Eutrophication: the accumulation of phosphorus and nitrogen in water, soil and air;
- Exhaustion of abiotic raw materials, mainly fossil fuel since marlstone or limestone are not scarce materials on a world-wide scale;
- Ecotoxicity: fluoranthene emission and propane production;
- Greenhouse effect: CO_2 and CH_4 emission
  Important here is that the contribution by Portland cement per kilo is three times greater than by blast-furnace cement. For the "hollow-core floor" 37.7 kg Portland cement is used per m² of floor and for the "shuttering slab floor" 16.0 kg Portland cement plus 43.8 blast-furnace cement per m² and for the "cast in-situ floor" 60.6 kg blast-furnace cement per m².
- Acidification: the deposit of acidification substances (NO,, SO_x, NH&
- Smog formed by the emission of hydrocarbons;
- Human toxicity by emission of NO_x, SO_x, CO and heavy metals.

Table 2 : Absolute values of environmental effects

	units	**hollow-core floor**	**shuttering slab floor**	**cast in situ floor**
Eutrophication	kg PO_4 10^{-3} eq.	0.0356	0.0448	0.0410
Exhaustion	10^{-12}	0.0468	0.062 1	0.0707
Ecotoxicitv	10^3m^3	2.78	5.52	5.81
Greenhouse effect	kg CO_2 eq.	55.2	58.6	53.4
Acidification	kg SO_2 eq.	0.252	0.321	0.306
ISmog	kg C_2H_4 eq.	0.0297	0.0453	0.0460
Human toxicity	kg	0.318	0.429	0.411

3 Basic problems for life cycle analysis

The most important problems related to Life Cycle Analysis (LCA)are:

- The selection of aspects considered in the analysis and their grouping in a manageable set of indicators.
- Definition of system boundaries: which steps of the production process are included and which are not, for example including production of energy carriers and all transport operations, but excluding production of capital goods.
- The gathering of reliable data for the different steps in the production. Improvements, as far as environmental aspects are concerned, require a regular updating of those parameters.
- If in one production step different (by-) products are obtained, an allocation of inputs and outputs over all the products has to be made.
- An integrated comparison: since in general some products will score better on some items and worse on others, the main problem is to develop objective criteria for the determination of ponderation factors for the different aspects.
- Waste and recycling: in this study 80% of the steel is (at the end of the 50 years) reused and 20% is unusable scrap; 70% of the concrete is reused for road construction, 20% is reused in new concrete and 10% is "lost" in the demolition process.

Each of the “problems” mentioned above requires a detailed technical discussion. In most cases pragmatic decisions have to be made since the elaboration of a “perfect” analysis will require an effort such that no results will be available in the near future. However, the danger arises that as a result, a single-value-indicator may be derived which will live its own life without all the critical considerations which should be added to this single value.

4. Pragmatic incorporation of key parameters

In view of all the methodological problems, one may suggest the formulation of the following policy:

- For dangerous emissions or for emissions which can easily be avoided, an interdiction should be imposed by the government (e.g. asbestos fibres for air ducts).
- Since many environmental effects (emission of NO_x, SOx,CH_4, CO, CO_2) are linked, directly or indirectly, to the use of fossil fuels, imposing an eco-tax on fossil fuels may be a pragmatic solution. Since the tax has to be paid for all the steps in the production process, the detailed reconstruction of the production chain is not necessary. In each step one will try to avoid as much as possible a high energy content. There is no “system demarcation problem” any more, even the energy for the production of capital goods is included. A socially acceptable transition period, where the cost of fuel increases from the present level to a socially acceptable level, has to be determined. Fundamental parameters are (Fig. 2): the final cost level (in real prices) (A and B), when the average between the current and the final level should be reached (A and C), how steep the slope will be (C, D and E).

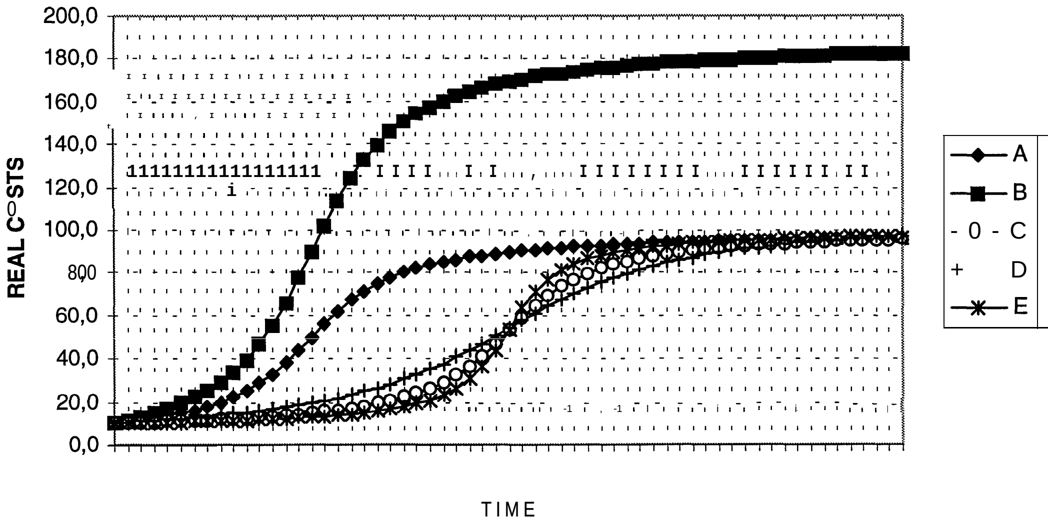


Figure 2 : Scenarios for the evolution of energy costs

5 Fundamental advantages of hollow-core floor system

What is the origin of the better score for the “hollow-core floor” in this analysis?

- First, the specific form of the floor section (I-shaped): the concrete is used in a more efficient way; there is less concrete in the middle of the floor element where the concrete contributes less to the resistance to bending forces.
- Second, the high quality concrete: since the concrete is processed in factory conditions, a closer monitoring of the process is possible, leading to a better quality and to less variation of the quality. This will lead to reduced safety factors without reduction of safety margins.
- Third, compared to the two other solutions, pre-stressed reinforcement of high quality steel ($Fe_{0.2}$ 1770/1860 instead of Fe 500) is used and so a reduction of the consumption of steel per metre square of floor is obtained.

6 Span as an important parameter

In the analysis presented above, the reference situation was a span of 5.4 m and a functional load for single family housing. Most pre-fabrication plants offer a range of floor elements with different thickness. In function of the superimposed load, when the span increases, one needs to use a thicker element. How the mass of concrete changes in function of the span for a given overload is represented in Fig. 3.

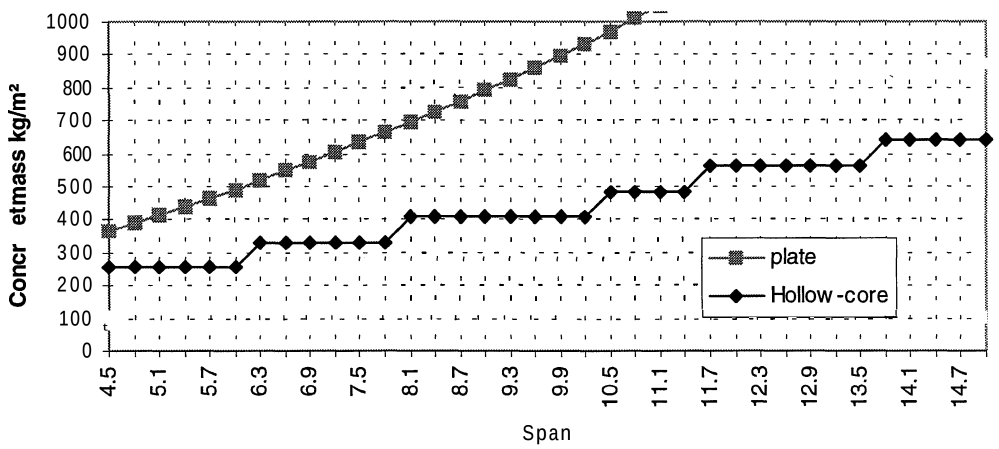


Figure 3 : Concrete mass /m² in function of span

The relation between the mass of concrete per square metre floor and the span (for the two types of floor) is also represented in Figure 3. The hypothesis here is that concrete and steel are used up to their limits. The longer the span the more significant the advantage of the hollow-core floor is in comparison to plate floor system. The inefficient use of concrete will, in the case of massive floors, lead to extra loads. From a certain span on pre-stressed elements are the only realistic solution.

7 Functional life time

By using longer spans, however, one also creates possibilities for changing the layout of the rooms without conflicting with the structure. This is extremely important for office buildings, hospitals, commercial buildings and industrial buildings. One should include in the environmental analysis the fact that, if one builds a structure with small spans, it may be unavoidable to demolish the whole structure after 10, 15 or 20 years. However, if a concrete structure fulfils the basic requirements of structural stability, fire resistance, acoustical insulation and other performance requirements, the structure may be in good technical condition for 60, 90 or even 120 years. If one considers the fact that with each demolition a fraction of the concrete (10% or more) and of the steel (20% or more) is "lost" and as well a significant amount of energy is required to demolish the structure and to transport and reuse the materials, the additional spending in larger spans may prove to be very efficient in terms of sustainability. Exact calculations require a number of hypotheses: e.g., end of functional life time, energy input for demolition and transport of recyclable fraction, type of new structure,. . .

8 Layout and sustainability

Linked to the question of selecting an appropriate span for the floor elements of a building is the problem of selecting the span of the beams [2]. For example, in the case of office buildings, the question is: is there (and will there be) a need for small cellular work spaces? (new needs due to expected speech-interactions with computers?); for landscape-offices?; or for a combination of working cells and open spaces? In function of the required flexibility, beams may be shorter or longer and may be provided in different positions (Fig. 4). One should not only look at the floor elements but at the structure as a whole including beams, columns, foundations and other elements of the

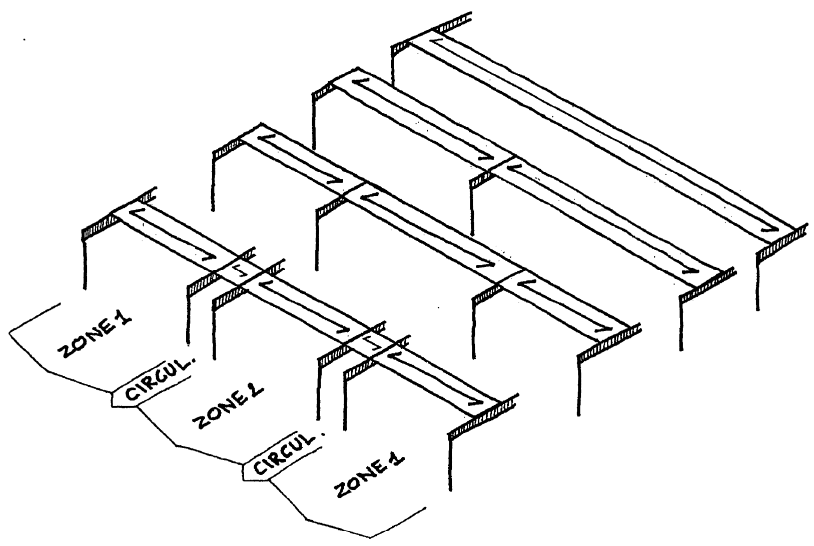
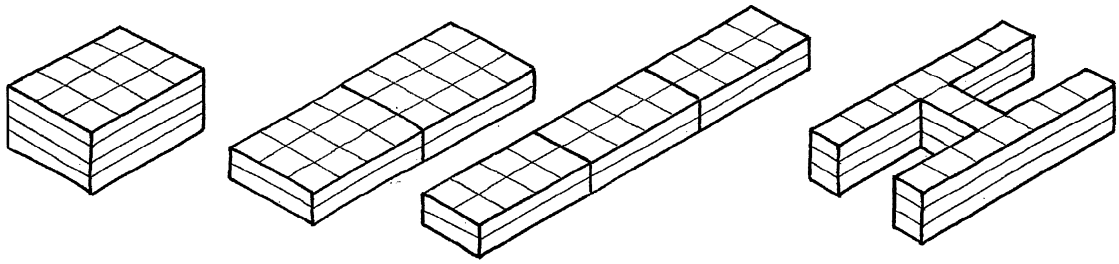


Figure 4 : Position of beams and span of floorelements

building.

In essence the decision is linked to the total depth of the building. Figure 5 shows four master plans for an office building. All of them have the same size. If we consider the quantity of roof, of external wall, of internal floor and of “floor on the ground” per square metre of usable floor, important differences are evident. These effects are controlled by the well established “element method for cost control”[3]. Following this method the cost per m^2 usable floor is obtained by the product of the unit rate of an element and the ratio of that element. The ratio is the “quantity of element/m^2 floor area”. For example in the case of a building with a ground floor and a first floor, the ratio for the first floor is 0.5 m^2 first floor/m^2 total floor. Ratios of some of the elements are mentioned in Table 3.



Plan 1 Plan 2 Plan 3 Plan 4

Figure 5 : Four different masterplans

Table 3 : Ratios for different elements (m^2 element/ m^2 usable floor)

	Plan 1	Plan 2	Plan 3	Plan 4
Roof	0.2500	0.5000	0.5000	0.3333
Internal floor	0.7500	0.5000	0.5000	0.6667
External wall *	0.5833	0.4583	0.5833	1.0625

* for basic block 6m x 6m x 3m

We can use as a “functional unit” (in the comparison of different answers to a need for usable floor area) one m^2 of floor area including all other building elements needed per m^2 floor area. Using this “ratio” not only are the quantity of inputs needed for the construction controlled, but also the present value of the costs per m^2 of floor for maintaining, demolishing, reusing and disposal. All of them are influenced by the layout and thus by the “ratio”. Different technical solutions for elements such as external walls, roofs and groundfloors will lead to other heat losses per metre square of those elements. The costs for heating per m^2 of floor area are linked to the cost per element via the “ratios”.

There is no direct link between the land use and the master plan: in fact it is possible to provide a very compact building on a very big plot. But it is impossible to reduce a plot more than the “footprint” of the building. Land use is not only important in the sense that land is a unique resource, but also because land-use-patterns determine energy consumption for transport.

9 Conclusions

The major advantage of building systems based on pre-stressed concrete floor-, roof- and beam elements is the reduction of the mass of concrete and steel used per m^2 of floor area (efficient form for bending forces, factory controlled concrete quality, high steel quality).For larger spans the advantages of pre-stressing are more significant. An often overlooked effect of using larger spans is that the same structure can easily be adapted to accommodate changing needs. This leads to a reduction of energy consumption for demolishing and recycling materials as well as to a reduction of the waste fraction.

Linked to the adaptability is the layout of the master-plan. Another layout has an effect upon the quantity of external wall, roof, groundfloor and other elements per metre square of usable floor area. In a more complete LCC-analysis, usable floor area should be used as a "functional unit" for comparison. Doing so also effects related to maintenance, repair, energy losses and other costs-in-use of elements such as external walls, roofs, groundfloors are linked to a square metre usable floor.

References

1. Fluitman, A., de Lange V.P.A. (1996) *Comparison of the environmental effects of three concrete storey floors*, CEREM, Amserdam.
2. De Troyer, F., (1996) *Syntheserapport voor het opstellen van een ontwerpgids voor beton prefab (Summary report for the elaboration of a design guide for prefabrication in concrete - only in Dutch),* KULeuven department ASRO, Leuven.
3. Kelly, J.,R., (1987) Report on Session B : Design optimisation. *CIB Proceedings of the fourth international symposium on building economics,* Danish Building Research institute, Copenhagen, pp. 1 1- 19.

RECYCLING WASTE AS BUILDING MATERIALS: AN INTERNET DATABASE

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Abstract
Environmental concern is expected to have serious implications for affect the construction industry in the years to come. The construction industry, including building materials production, is probably the greatest consumer of natural resources, using between 17 to 50 % of those available. Recycling wastes both from construction and other industries is one important alternative to reduce the impact of construction activities on the environment.

However there are some constraints in using recycled waste as building materials , due to lack of information, research and development technology. Market and technology differences between countries make some recycling technologies successful in some instances but not in others.

An methodology outline for guiding research and development of building materials from recycled waste is presented in this paper and it's main steps are summarized.

Waste characterization is the first step of the study. The selection of possible applications for the waste must consider both the technical and market aspects. Laboratory research must be based on a scientific approach and performance concept. Durability evaluation is an important phase of the study and the service life of any new material will affect not only its economical feasibility but also its environmental impact.

A web site including a database about recycling waste as building material has been build and is available on the Internet. The database includeswaste and some basic information aboutthem, references and reports with researchers names. It is possible to everybody feed the database with new information. The address of the web site is http://www.recycle.pcc.usp.br.
Keywords: Recycling, methodology, database, Internet, sustainable development

1 Introduction

Environmental consciousness is considered as being one of the most important trends in the construction industry [1].

The construction industry, including building material production, is probably the greatest consumer of natural resources, using from 17 to 50 % of the extracted „resources, as water, wood, minerals and fossil fuels [2]. These figures are probably greater in poorer countries. The consumption of natural rock for aggregates to make concrete, asphalt, and road base ranges between 1 to 7.7 tones/year/inhabitant [3]. One author estimate that building construction uses about 66 % of the virgin wood, a potentially sustainable material [4] but only 20 % of the tropical forests that supply most of hardwood are managed in a sustainable way [3]. Some of the materials consumed on a large scale are subject to shortage in the near future. These include copper and zinc, which have estimated reserves for about 60 years [5].

The construction industry is also one of the biggest waste generator in the economy. In developed countries like USA and Germany, the amount of waste generated by the construction industry is comparable to municipal solid waste generation [4]. In the big cities of poorer countries like São Paulo, the waste generated by construction and demolition activities is 2.3 times greater than the municipal solid waste [6]. Almost one third of this construction waste is illegally placed outside of landfill, polluting the environment, obstructing rivers, and promoting floods during the raining seasons. For each tonne of steel produced about 700 kg of waste are generated, including about 300 kg of blast furnace slag.

The construction industry also generates air pollution ranging from CO_2 during limestone burning to airborne particulate material during site operations.

Reducing the environmental impact of the construction industry is a complex situation and certainly will include the environmental motif "Reuse, Reduce and Recycle". Re-using building components and reducing the consumption of energy and raw materials, including making the building more durable, will play an important role. But no matter how much the industry succeeds in reducing the natural materials consumption, making and maintaining buildings, roads, bridges will always consume large amount of materials and recycling waste produced by different industrial sectors seems to be vital.

2 Main recycling constraints

The construction industry has a long history on recycling. Recycling granulated blast furnace slag as a hydraulic binder, for example, started at the beginning of the 19th Century and in the beginning of the 20th Century the Portland slag cements were on the market and covered by standards [7]. Despite of the technical and environmental advantages of this kind of cement, it is not permitted to mix Portland cement with slag in some countries, like Argentina.

These differences in recycling policies between countries are not exception but a rule. Colliery spoil from coal extraction is recycled in China and the UK [3] but not in Brazil. This happens because recycling waste has some constraints.

2.1 Market differences

Differences in building materials market between countries or regions are frequently important. These differences can make one recycling technology economically viable in one region but not in other one. It occurs specially because the environmental impact of recycling is not considered at all in most of countries.

2.2 Lack of suitable research methodology

Standards and regulations, including those that are related to solid waste disposal and classification severely restrict recycling possibilities [9]. Most solid waste regulations are concerned about waste disposal and contain no rules that facilitate recycling. Standard leaching tests, for example, are developed to control groundwater contamination by a landfill, which can concentrate huge amount of dangerous waste. It clearly doesn't apply to a waste widespread over a large area, like when a waste is recycled as building material. In addition, it does not take into account the decisive influence of the size, shape, water absorption, and evaporation that causes leaching in real materials as well as the influence of the environment.

The main problem here is probably the lack of a consolidated and widely accepted systematic methodology to guide research and development and environmental risk evaluation for recycling technology. On the other hand , technical standards for the building industry almost enforce the use of traditional materials and components. Technical Approval's schemes, must also rely on a systematic methodology for environmental risk evaluation, could be a good solution to this problem. In addition, eco-label schemes can made good recycled products even more attractive to consumers.

2.3 Construction technologies

Differences between indigenous construction technologies also have a similar effect on the development of any recycling market.

2.4 Lack of information

Lack of reliable information about both successful and unsuccessful recycling technologies and expertise also plays an important role. Most waste producers have little association with the building industry and for this reason, they are not able to foresee possible applications. If they do succeed in detecting an application, they often take a long time seeking researchers with proper experience in develop new building material from recycled waste. Lack of information also affects research activities. The lack of knowledge about potentially recyclable waste can partially explain the concentration of research on blast furnace slag and fly ash. A web-site can contribute to widespread information about waste and recycling waste as building materials.

2.5 Recycling strategy

A poor recycling strategy can also contribute to keep some waste out of the recycling process. Most industries try to sell waste as waste, and as such, the consumer of the waste have to have the knowledge of recycling. This strategy works for some simple recycling technologies that are easy to develop or for those tremendously profitable. However, in most cases no potential consumer wants to bear the risk of financially supporting the research and development of a recycling technology for a product that belongs to someone else. The high cost of waste deposition and possible profits of recycling can however persuade a waste producer to invest in research and development.

3 Recycling research and development methodology

A recycling research and development project is always a comprehensive and multi-disciplinary study. A proposed outline of a methodology is presented.

3.1 Waste characterization

The first step in any research and development project must be the characterization of the waste, including any production parameter and a comprehensive physical and chemical analysis which considers it's variability with the time and environmental risk.

3.2 Selection of possible application

The next and the single most important step is selection of possible applications must consider both the technical and market aspects. From the technical point of view there is frequently more than one possibility for recycling. The selection of the most suitable alternative depends upon market evaluation, which must be based on a comprehensive knowledge of both the construction market and construction technology as well as a good estimation of the economic feasibility of each alternative.

Developing a cheap material may not lead to success in the market. For example, blast furnace slag activated with lime or sodium hydroxide was on the European and even North American market until the end of the 1940's. Even though this cement was cheaper than Ordinary Portland Cement, it vanished from the market because of it's poor performance regarding frost resistance and low initial strength [7]. Finding an application where the new product has a better performance than any other alternative already in the market is the most important thing.

Economical feasibility must be evaluated by comparing the cost of waste disposal in an authorized landfill against the cost of recycling.

3.3 Product research and development

It starts with very basic research and goes on to a complete performance evaluation, which includes durability and environmental impact. Development of the process of production, including the appropriate quality control tests, must also be covered.

The research must be conducted on a scientific basis in order to ensure complete knowledge about the new material properties. The evaluation of the new product must be carried on by considering its fitness for the purpose. It could be based on CIB W 60 [10] methodology and IS0 624 1.

Indoor air quality must be carefully considered when studying wastes containing volatile organic components. The use of standards developed specifically for traditional but similar material or components is not adequate and can give the wrong results. Tests must elucidate the main degradation factors, degradation mechanisms and the effect of these processes on the performance.

Not all recycling is environment friendly and therefore environmental impact has to be evaluated on cradle-to-grave basis.

3.4 Technology transfer

Unfortunately, few research programs dealing with recycling have been designed to facilitate the transfer of developed technology to the market and for this reason, most of them never reach the production stage.

Technology transfer must be planned from the very first phase of the research. Successful joint research and development projects will include a research institution, the waste producer and a company that expects to manufacture the new material. Of course, selecting the appropriate application for the waste is also critical.

Wide dissemination of research results to building entrepreneurs and consumers is also helpful to create good expectations in the market before the product is actually ready to be sold.

After the development is completed is important that the researchers give continued support to the producer to ensure the product get a technical approval and the proper environmental certificates.

4 Diffusion information using an Internet database

As mentioned previously, dissemination of information on potentially recyclable waste, research expertise and any research results could not only help other researchers but the society in general.

It has been the aim of this research programme to develop a database that is accessible through Internet by a plain Web connection. This database include:

1. Internet data sources and web-sites;
2. Potentially recyclable waste as building materials and their main characteristics
3. Waste recycling alternatives, both proved or possible;
4. References of papers and reports;
5. Researchers names, including the addresses if available.

The database is a relational one, built over a SQL server. It is fully indexed using a controlled vocabulary, making it easy and reliable in any search. It is possible feed the database with new information which will be available at the web site as soon as its consistency is checked.

The web site also includes short reports and texts and its address is http://www.recycle.pcc.usp.br.

5 Final remarks

Environmental concern is expected to deeply affect the construction industry in the years to come. Recycling wastes both from construction and from other industries is one important alternative to reduce the impact on the environment.

There are many constraints which make it difficult to develop a waste into a new material. These constraints include lack of information, lack of research methodology, poor recycling strategies from waste producers as well as differences in market and construction technologies between countries.

The development of a new product through waste recycling must include product characterization, careful evaluation of the market and technical acceptance of the recycling option, a scientific based research that includes the evaluation of the environmental impact of the recycling, as well as technology transfer.

6 Acknowledgement

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7 References

1. Bernstein, H. (1996) Bridging the globe: creating an international climate of engineering and construction innovation. *Industry and environment,* Vol. 19 No.2. pp.26-28
2. Editors (1996) The construction industry: building for sustainability? *Industry and environment,* Vol. 19 No.2. pp.3
3. Editors (1996) Construction and the environment: facts and figures. *Industry and environment,* Vol. 19 No.2. pp.4-8
4. Roodmann, D.M.; Lenssen, D. (1994) Our building, ourselves. *World Watch,* Nov/Dec 1994 pp.21-29
5. The Global Tomorrow Coalition (1990) Minerais não combustiveis. *The Global Ecology Handbook.* São Paulo : Augustos, 1996 p..175-188
6. Pinto, T. P. (1997) Reciclagem de residuos da construção urbana no Brasil – Situação Atual. *In: Workshop Reciclagem e Reutilização de Residuos como materiais de construção civil.* São Paulo : ANTAC, pp. 159-70 (in Portuguese)
7. Sjöström, Ch. (1996) Durability and sustainable use of building materials. *Sustainable use of materials.* BRE / RILEM, 23-14 Sept. 1996
8. John, V. M. (1995) *Cement made with grounded blast furnace slag activated with sodium silicates.* São Paulo : USP, 200p. (Ph.D. Thesis, in Portuguese)
9. Pera, J. (1997) State of the Art Report – Use of Waste Materials in Construction in Western Europe. *Workshop Reciclagem e Reutilização de Residuos como materiais de construção civil.* São Paulo : ANTAC, pp.1-20
10. CIB (1983) *Working with Performance Approach in Building.* Rotterdam : CIB, (CIB Publication 64).

Effect of latex paint compositions on the water transport mechanism

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Abstract
Absorbed water is the main deterioration factor of building materials, mainly for external wall surfaces. These surfaces can be protected by paints which may reduce the volume of absorbed water from external sources. At the same time, mould growth on coated external wall surfaces is also an important durability problem. A knowledge of the degradadion factors is important for increasing the service life of paintwork and for reducing maintenance costs. The rate of absorption and evaporation of water through the paint film affects the moisture content in the substrate. This property is also related to the time of wetness which affects the growth of fungus. In order to understand the water transport mechanism, the water absorption and evaporation of latex paints with different pigment/binder ratios was studied. The tests were done applying paints to mortar and concrete substrates. The results show that there is a correlation between paint composition and the rate of absorption and evaporation of water. Furthermore, the study also showed that acrylic latex paints provide a good barrier to water penetration. However, the substrate also has an effect on water transport mechanism. It was concluded that a functional substrate reduces the absorption and evaporation rates of paints, it is recommended to dry the substrates and protect them with acrylic paints. Improving the knowledge of the paints it is possible to increase the durability of the painted wall without adding toxic ingredients and doing so avoiding human and environmental hazards.
Keywords: humidity, latex paints, mould growth, permeability, service life, maintenance costs, degradation factors, time of wetness

1 Introduction

The external walls of buildings built in São Paulo are usually composed of mortar and concrete which are porous materials, and therefore permit water penetration from rain and wind. Absorbed water is the main deterioration factor of building materials. In order to prevent water penetration, the walls can be protected by paints that provide a polymer film barrier on the wall surfaces by reducing the volume of water transported through them. As such, coatings have an important role in limiting water penetration into the wall. As well, the availability of water in building materials is the key factor that leads to the growth of microorganisms. Microbial growth in external painted façades is considered to be one of the major and more significant maintenance problems in particular throughout the sub-tropical and tropical regions of the world [1,2]. Therefore, the presence of biological microorganisms is the most significant factor in the performance of paints in the regions when aesthetic performance is of prime importance. Usually these organisms are not destructive but they do produce disfiguring stains on wall surfaces.

Paints are formulated products designed to provide both a decorative finish and to protect the underlying substrate from environmental effects. They contain binders (resins), pigments, fillers, stabilizers, surfactants, solvents and thickners. The binder, sometimes called the vehicle, is essencial for film formation. The composition of the binder is of major importance to the film's properties, even though these properties are also modified to a considerable extent by the use of pigments. The pigments not only control color, gloss and hiding power, but also affect the strength and permeability of the paints [3].

It is necessary to consider the effect of the proportion of pigment in the paint in order to achieve a proper dispersion. This proportion is expressed as the pigment-binder ratio (P/B), usually calculated on a volume basis. For instance, the gloss decreases as the pigment-binder ratio increases but the relation is not a simple one and the changes are normally most rapid in the range from 0.9: **1** to **1.1: 1** [3]. An alternative way of expressing the same information is in terms of the pigment volume concentration (PVC) - the volume of pigment expressed as a percentage of the total volume of dry film (pigment volume + vehicle solids volume) [4]. The porosity of film is related to the type and content of pigment used. Films of paints with high PVC content present high porosity and consequently high permeability to water and water vapour.

This paper presents part of a research work dealing with mass transfer studies in order to improve the durability of building materials. It is an attempt relate to the volume of water transport through a latex film in relation to different pigment/binder ratios.

2 Experimental procedure

To evaluate the performance of paints in inhibiting the ingress of water in a substrate and to determine the drying process as well as understand the water transport mechanism through latex paints, 8 paints with a different PVC were applied on one mortar and two kinds of concrete substrates. The method used is based on the comparison of measurement of the water absorption by capillarity and evaporation over a length of time in painted and unpainted substrates.

2.1 Materials

2.1.1 Mortar

The mortar samples were prepared in laboratory, with CP II-E Brazilian Portland cement (ordinary Portland cement with addition of BFS up to 34% in weight), hydraulic lime and medium river sand, with a commonly used mix proportion (1:2:9, by volume). After casting, the mortar specimens were kept 7 days in a wet chamber having 95% relative humidity and then stored more than 30 days in a laboratory environment having 25 ^{o} ± 2 ^{o}C and 50 ± 5 % RH.

2.1.2 Concrete

Two differents concretes were used in these tests: one having a relatively high strength (40MPa and w/c 0.44) and the other with ordinary strength (20MPa and w/c 0.76). They were prepared using CP II-E Portland cement, coarse crushed aggregate (maximum size of 19 mm) and medium river sand. After casting, the concrete specimens were kept 7 days in wet a chamber having 95% relative humidity and then stored 21 days in a laboratory environment having 25 ^{o} ± 2 ^{o}C and 50 ± 5 % RH.

2.1.3 Paints

Latex paint products commercially available in São Paulo and commonly used in exterior building walls were collected for the study. The products consisted of pigmented latex, with PVAc and acrylic binder from different manufacturers, each having different gloss and matt finishes. The products were applied according to manufacturers' instructions: two coats were applied to all specimens and cured for two weeks. Table 1 shows the main characteristics of the emulsion paints and the pigment/binder ratio (g/g).

Table 1 - Characteristics of the paints

Product	Solid content (%)	Pigment content (%)	Binder content (%)	Pigment/binder ratio
Acrylic 1 (gloss)	50,2	24,3	26,0	0.9
Acrylic 2 (matt)	56,5	40,2	15,7	2.6
Acrylic 3 (gloss)	45,8	24,4	21,8	1,1
Acrylic 4 (matt)	49,3	37,6	11,7	3,2
PVAc 1 (matt)	50,7	36,1	14,6	2,5
PVAc 2 (matt)	40,4	31,2	9,24	3,4
PVAc 3 (matt)	51,9	45,6	6,32	7,2
PVAc 4 (matt)	49.1	33.8	15,2	2,2

2.2 Methods

2.2.1 Water absorption

The testing methods were based on the British Standard [5] with a few alterations to cope with the purpose of this research work – water transport mechanism study. Mortar and concrete specimens with 10cm x 10cm x 2cm were sealed with a silicone sealant on the 10cm x 2 cm dimensions faces. One set of these specimens was used as reference samples and another set had one of the unsealed faces painted. The 10cm x 10cm dimension surfaces of both the painted and the unpainted sets were faced down on deionized water, with those of the painted face placed painted side down. The gain of water was determined by weighing the specimens at predetermined time intervals. The measurement was done until the unpainted reference samples achieved complete saturation. The tests were done in an environment with 50-60% relative humidity and a temperature of 25°C. The results were plotted shown in terms of mass change as a function of time.

2.2.2 Evaporation of water

After the water absorption test, all specimens were partially immersed in water with the unpainted surface face down, until saturation of the substrates. Later, this face was sealed with aluminium foil and the specimens were allowed to dry with the unsealed surface exposed to an environment with 50-60% relative humidity and 25°C. The loss of water through the unsealed face was measured by weighing at predetermined time intervals, until a constant weight was reached.

3. Results and comments

3.1 Mortar substrates

The water absorption and evaporation characteristics of the mortar substrates was determined in relation to the eight latex paints. The relative change of water content in test specimens, unpainted and painted with PVAc latex and acrylic latex is shown in Figure1 to 4.

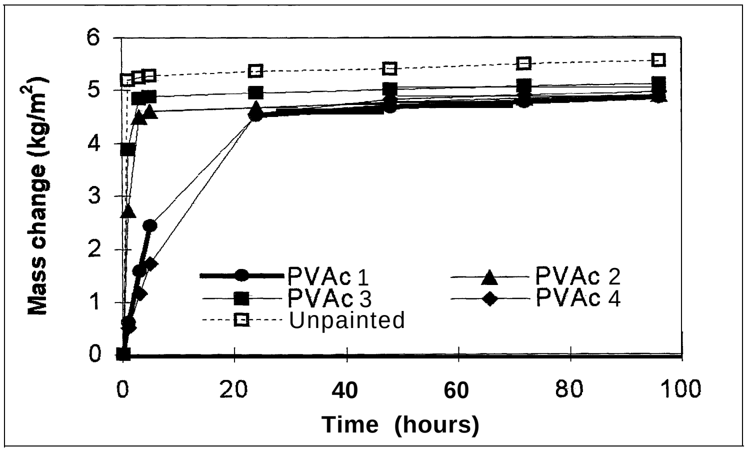

Figure 1 Water absorption of mortar, unpainted and painted with PVAc latex

The tests carried out in specimens painted with PVAc latex paints, with different pigment/bider ratios, showed similar performance. The water absoption after 96 hours immersion was reduced bv not more than 20% for all the painted surfaces when compared to the unpainted one.

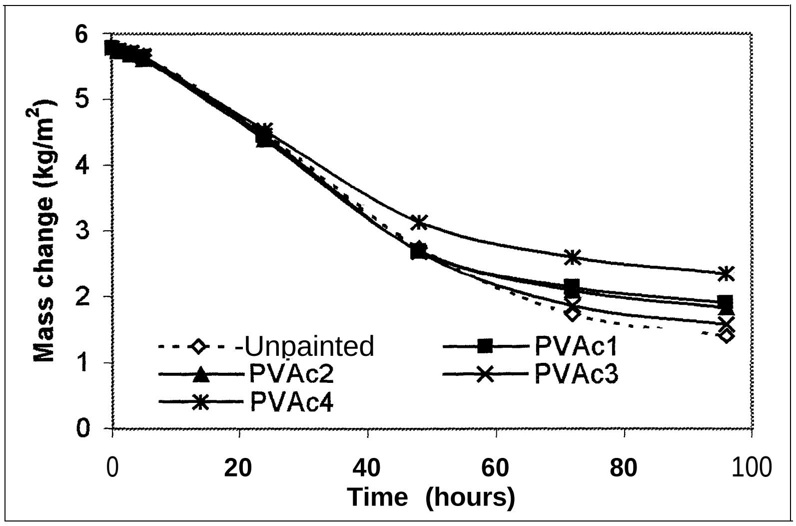

Figure 2 Water evaporation of mortar, unpainted and painted with PVAc latex

The evaporation rate after the same period showed a relative reduction of 10-26% after 96 hours of drying. In general, the effect of PVAc paint on water transport reduction was not significant. Moreover, as the paints are from different manufacturers the binder composition may be different and this most likely masks the possible effects of the P/B ratio on the transport properties of the paint. Therefore although products PVAc 1 and PVAc 4 provided relatively better results in relation to the other products, these are not clearly evident from the results.

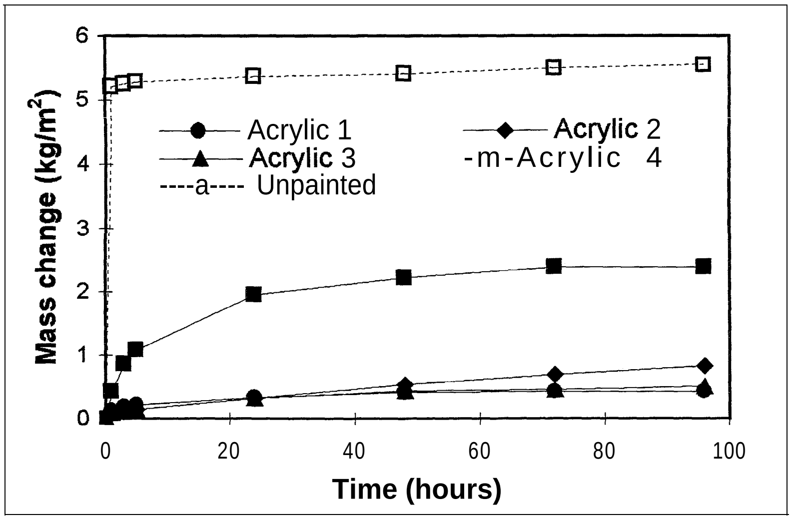

Figure 3 Water absorption of mortar, unpainted and painted with acrylic latex

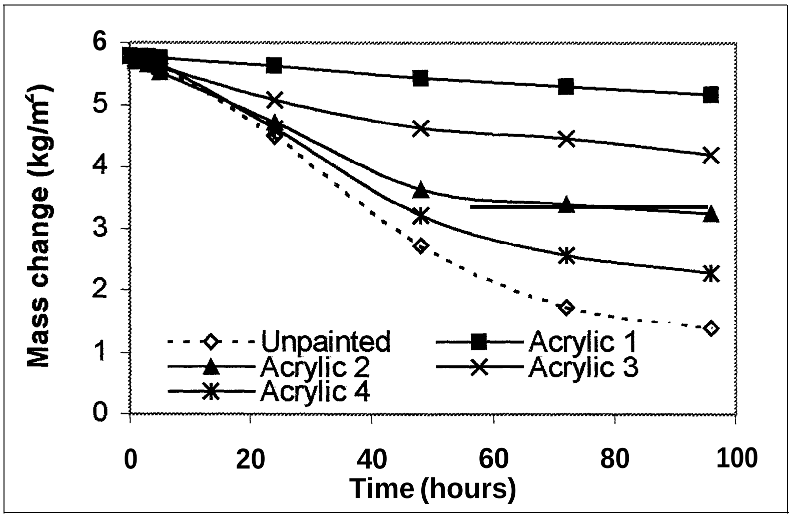

Figure 4 Water evaporation of mortar, unpainted and painted with acrylic latex

The same tests carried out on specimens painted with acrylic latex paints showed that **3** of them have a very similar performance and only the Acrylic 4 behaves differently. This is because the paint Acrylic 4 paint has a considerably lower binder content in comparison to the other products. The Acrylic **1, 2** and **3** products (low pigment/binder ratio) showed a relative reduction of 90% in water absorption. It is possible to conclude that these types of coatings provide an actual barrier to water penetration however, the evaporation process is retarded.

3.2 Concrete substrates

From the previous results, this part of the study was carried out with the two acrylic paints produced by the same manufacturer but having opposite performance. Figures 5 and **6** show the relative change of water content in test specimens, unpainted and painted with acrylic latex, gloss and matt finishes.

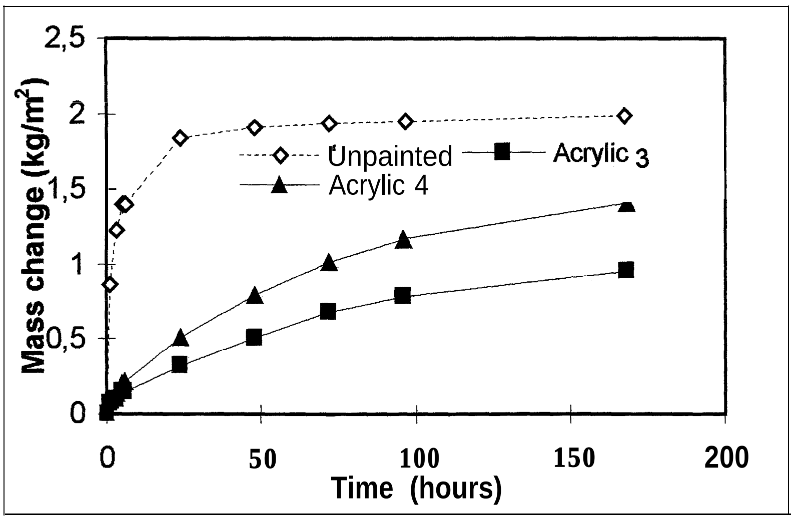

Figure 5 Water absorption, concrete (20MPa), unpainted and painted with acrylic latex

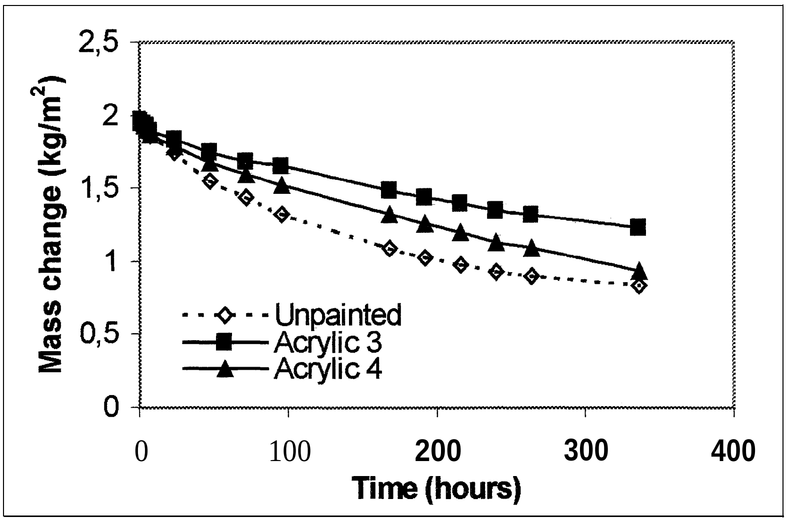

Figure 6 Water evaporation of concrete (20MPa), unpainted and painted with acrylic latex

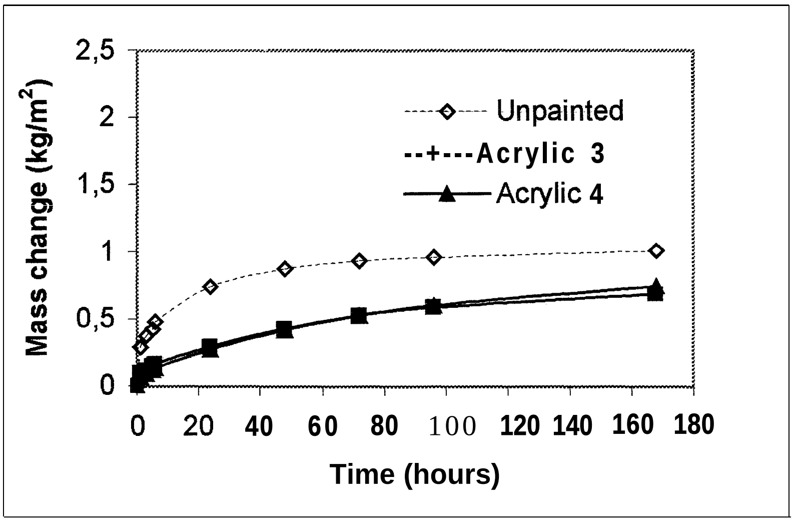

Figure 7 Water absorption of concrete(40MPa), unpainted and painted with acrylic latex

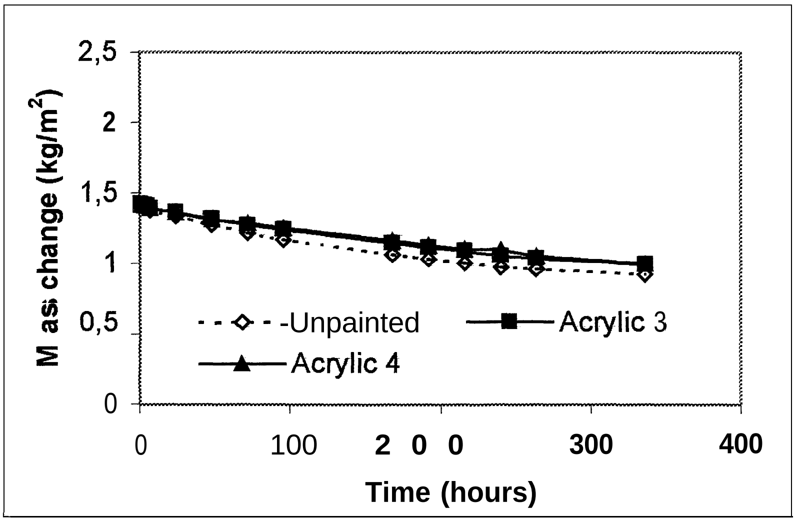

Figure 8 Water evaporation of concrete (40MPa), unpainted and painted with acrylic latex

The tests carried out on ordinary concrete (20 MPa) specimens painted with acrylic 3 latex paint (gloss finish and low pigment/resin ratio) showed a relative reduction of 50% in 168 hours of water absorption, but acrylic 4 (matt finish and high pigment/resin ratio) showed a relative reduction of only 30% in water absorption. These types of coatings provide a good barrier to water penetration although the evaporation process is also retarded. Therefore it appears that the binder content affects both the water absorption and evaporation rates.

The tests carried out on high strength concrete (40 MPa) specimens painted with acrylic latex showed that the substrate also has an effect on absorption and evaporation rates as the values are quite different from those obtained on specimens painted on ordinary concretes (20 MPa) (Figures 5 and 6).

4. Conclusions

As was expected, the pigment/binder ratios play a major role in the performance of the paints, as they affect the moisture content of the wall. However, there is no data available about the moisture content considered suitable for this purpose in international or Brazilian standards or codes, nor are results of published research. As claims from users are very frequent, the strategy adopted by producers has been the washing of painted surface with biocidal products and recoating the walls with a fungicidal quality paint. The major achievement of this paper is to demonstrate that with a better knowledge of paints it is possible to increase the durability of the paintwork without adding toxic ingredients and so doing, avoid human and environmental hazards.

It is possible to conclude that PVAc based paints present basically an aesthetic function, as the absorption process is rapid for painted mortar substrates and the drying process is slightly slower. The water is absorbed very easily and the residual water is not easily eliminated, creating good conditions for mould growth in rainy seasons.

Acrylic latex paints provide a good barrier to water penetration although the evaporation process is very retarded and the residual water is not easily eliminated. As, substrates with high water content present good conditions for biological microorganisms growth. These paints have to be applied only in very dried substrates to avoid creating good conditions for mould growth.

The substrate also ‘has an effect on the water transport mechanism. The concretes with low water/cement ratio itself present low absorption and evaporation rates. It is possible to conclude that a low permeable substrate does not need protection against water penetration. In summary, it is recommended to dry the substrates and protect then with acrylic paints.

Acknowlegments

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References

1. ÓNeill, T.B. **(1986)** Succession and interrelationships of microorganisms on painted surfaces. *Journal* of *Coatings Technology*, Vol. **58, No 734.** pp. 5 **l-56**
2. Sato, N. M. N.; Vittorino, F. , Agopyan, A, Uemoto, K. L. **(1995)** Penetração de umidade e crescimento de fungos em fachada. In: *Entac - Encontro Nacional De Tecnologia Do Ambiente Construído.* Rio de Janeiro.
3. Tyssal, L. A. (1964) Industrial paints: Basic principles. Pergamon Press Ltd, London.
4. ASBECK, W. K. (1992) A critical look at CPVC performance and aplications properties. *Journal of Coatings Technology*. Vol. 64, No. 806, p.47-58.
5. British Standards Institution (1992) Water repellents for masonry (BS 6477).

A causal path model to evaluate the environmental impact of frame materials.

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Abstract
The previous decade has seen an increased emphasis placed upon assessing new construction projects in relation to the impact that they have upon the environment. The impact of construction projects upon the environment requires to be appraised both in relation to the product, in terms of Life Cycle Assessment (LCA) and in relation to the processes that are employed to produce it (Environmental Effect Assessment). In this regard, to properly understand the impact of construction projects upon the environment, it is necessary to analyse the resource consumption for the production of new buildings; to analyse the level of waste that is involved in the production process; to undertake Life Cycle Assessments for each component, product and material incorporated within buildings; and to analyse the deconstruction methods available for the disposal of construction assets at the end of their usable lifespans. The material used to construct the structural frame within commercial buildings is considered to be of importance in connection with understanding the impact that contemporary construction projects have upon the environment in relation to the aforementioned analysis.

Research work at Napier University has developed an approach to assess the significance of the frame material in relation to the environmental impact of building projects. This approach is based upon a causal path analysis that is considered to be particularly suitable for quantifying the relative importance of individual variables in an overall set of interrelated variables that are expected to influence a given dependent variable. The method is appropriate for testing intuitive ideas or beliefs concerning which variables are of most importance in determining an outcome in a statistically rigorous manner.

This paper presents the results of this research towards developing a full causal path model which will provide for a quantitative evaluation of the relative importance of alternative frame materials upon the overall environmental impact of building projects in connection with the assessment criteria detailed.
Keywords: Frame material, environmental assessment, causal path modelling.

1.0 Introduction

The UK market for framed building structures of two or more storeys is estimated at £1.5 billion per annum. Approximately £390 million of that figure is expended per annum on the construction of in- situ concrete frames. The remainder is expended on the construction of steel frames. Thus the share of the frame market presently held by steel construction is considerable. However, the concrete industry is presently challenging the present position by rigorously investigating its effectiveness and efficiency in order that it may compete with the steel industry in the area's where it is generally accepted that steel framed construction has major benefits; principally in relation to the speed of erection and the technical precision of frame assembly. To achieve its aims and to grow its market share, the concrete industry has involved itself in a £1.2 million research programme having as its principal aim the overall improvement of concrete frame performance [1]. The European Concrete Building (ECB) Programme (established by companies and trade associations working in the concrete industry and in its supply chains together with the UK's Building Research Establishment (BRE)) has provided the impetus for the above research programme, which aims to improve the quality of concrete design, to reengineer the concrete frame construction process and to improve structural performance.

Designers and concrete practitioners believe that the traditional design codes are too conservative and that, being based on individual elements, they do not appropriately appraise the inherent strength of a complete structure. As a result the above research programme sets out to rigorously investigate features such as thin plate floors, unobstructed soffits and pre- manufactured steel cross bracing and shearheads.

2.0 Requirement for an environmental appraisal

Clearly, the competition between the different frame materials as briefly described is presently based very much upon technical performance issues and upon on- site assembly processes which relate mostly to the time period which elapses between beginning work on the structural frame itself and allowing subsequent building assembly tasks to commence upon that frame. Such a basis for competition is not considered to be entirely inappropriate, since the efficiency of constructing the frame for buildings of two or more storey's is clearly of importance not only to the overall construction cost borne by the client organisation, but also to the overall construction time and, therefore, to the overall success of building project delivery from the client's perspective. However, it does mean that the primary basis of competition between steel and concrete frames is presently focused upon only technical and economic criteria. Little or no regard is paid to the differences which may exist between steel and concrete frames in relation to their overall impact upon the environment, throughout the life cycle of the construction project. With the exception of studies carried out to compare the in-use thermal performance of concrete and steel framed structures, little work has been undertaken to compare the environmental performance of the structural frame in relation to its role in the overall environmental impact produced by the building project process.

This study aims to address this deficiency and begins to address the process of applying environmental analyses in the complex case of the overall processes that are involved in the contemporary building project. The work is preliminary, however, a provisional causal path analysis model has been developed in an attempt to quantify the importance of the frame material in determining the overall impact of new construction projects upon the environment. Considering the demands which are now placed upon construction projects to be sustainable and environmentally sound, and considering the competition between the steel and concrete industries in relation to the future provision of structural frames, the present work is considered to be both appropriate and timely.

3.0 Environmental analysis

3.1 Basic environmental impact analysis

Environmental analysis techniques are relatively new and academic investigation of these is continuing towards developing agreed codes and standards that should be adhered to when undertaking environmental evaluations. Historically, the evaluation of products in relation to the impact that they have upon the environment has generally examined four main areas; namely, the energy use involved in their production, the air pollution involved, the water pollution and finally, the level of solid waste involved. Contemporary studies continue to examine these areas, however, the scope of environmental analyses has been extended. At the present time an appropriate environmental assessment may be considered to comprise an analysis of the environmental effects which are related to:-

- Resource consumption;
- Pollution (waste, emissions and discharges); and,
- Social and Welfare effects;

In attempting to realise the objectives of the present research, it is considered appropriate to investigate the environmental differences between steel and concrete framed structures in connection with the environmental effects of each over the whole life cycle of the contemporary building project.

In this regard *Life cycle assessment* (LCA) is of principal importance. LCA has been defined as a systematic inventory and a comprehensive assessment of the environmental effects (ie. resource consumption, Pollution and Welfare effects) of two or more alternative activities involving a defined product in a defined space and time including all steps and associated products involved throughout their life cycles [2].

In other words, a life cycle assessment is a comparative evaluation of *all* aspects of particular products, which must by definition must serve a specific function, as they relate to the environment (the products which are the subject of the assessment may be termed the *primary* products). Furthermore, it is an analysis of the environmental effects that are associated with all of the complementary products and processes which are introduced to a particular system by the selection of the primary product.

3.2 The inapplicability of existing analysis methods

The process of undertaking an environmental life cycle assessment is highly data intensive and rigorous and requires a series of relatively well defined steps and procedures to be followed. The products in question, the associated performance specifications and the functions require to be analysed to ensure that the investigator is undertaking consistent comparisons. However, the life cycle assessment process is not concerned with the comparison of particular products themselves but is rather concerned with the function that must be realised; the products are subsequently analysed in an attempt to determine which most appropriately (in terms of environmental effects) delivers the identified function. In conventional life cycle assessments, the function may be quantified in terms of *the functional unit of product.* Thereafter (in theory at least), the products being assessed in a given LCA should deliver 'equal amounts' of the identified functional unit in order that a valid comparison is realised. The environmental effects are then assessed in relation to the delivery of that function. This is relatively straightforward for a well defined product or service which has a clear function that is to be realised by its use. The most basic function of a structural frame may be described in terms of a requirement to transmit the loads in a building (quantified in kN per m^2) safely from the points where they occur, to the building foundation.

This is the most fundamental definition possible, however, obtaining a measure for the ***functional unit of product*** from this definition is not straightforward. First, the total loads to be supported by the frame are dependent upon the frame material. Therefore, a distinction must be made between the live loads and the dead loads; the latter being determined principally by the frame material. Second, the live loads to be supported by given frame are determined by the functional purpose of the building itself (rather than the frame). In other words, the live loads to be transmitted by the frame for a shop are substantially different from those for an office. Consequently, to validly assess which material is most appropriate for the structural frame in buildings generally, in relation to the environmental impact, a series of conventional LCA's are required in relation to different building types. Third, it is arguable whether or not a structural frame may be considered to be a ***product*** in itself. Rather, it is a sub- product of a building which is itself the usable product. This, of course, does not mean that an LCA using a functional unit of product defined in relation to the load per square metre to be transmitted safely to the foundations would be inappropriate. However, it is a fact that the material selected for the frame has so many substantive effects upon the design and construction processes and the completed building product itself that the product and sub- product analysis chains are vast and immensely complex, making the process of data gathering and analysis for a conventional LCA approach intractable and impractical. Many of the implications related to the selection of a particular frame material are not directly related to the fundamental function of the frame itself (as this has been defined), however, they do nevertheless have conceivable environmental effects which do require to be analysed in order that a comprehensive assessment is delivered. Figure 1 illustrates some examples of the complexity that is involved in relation to the effects of the chosen frame material (this is a simplified representation and by no means does figure 1 illustrate the overall complexity that is involved).

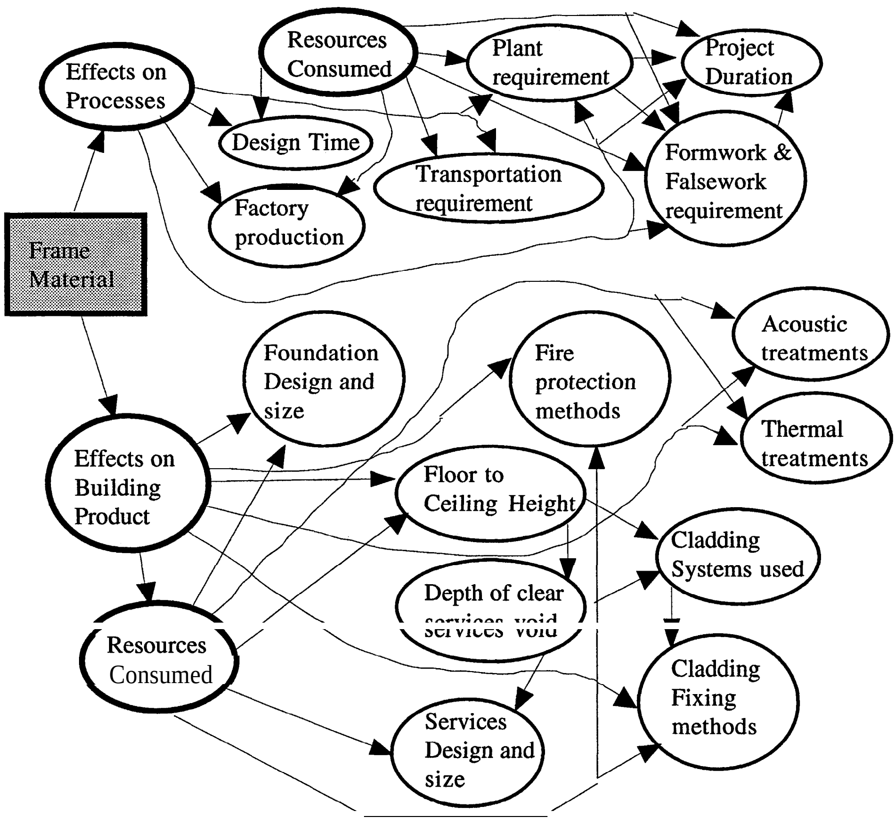


Figure 1 ***Simplified relationships between the frame material, the construction process and the building product.***

The relatively easy approach of analysing the environmental effects associated only with the materials; steel and concrete (in connection with the resources used to produce them, the pollution associated, and the social and welfare effects) would be wholly inadequate in any attempt to properly understand the true environmental impacts associated with the use of either a steel or a concrete frame considering that each frame type must include within it the use of ***both*** materials. Furthermore, as previously mentioned, the choice of frame material impacts many aspects of building project design, construction, use, maintenance and disposal, some of which are seemingly unconnected with the actual materials used.

An approach providing a comprehensive assessment of the total environmental effects of the frame material would be to view the building itself as the product, defining the functional unit of product in relation to the provision of square metres of usable space (the frame is, of course, very significant in realising this provision). This allows for an appropriate basis of comparison, that is the usable-building, and would capture analysis of all of the implications that the choice of a particular material for the frame has upon the overall fabric-and specification of a building together with the processes that are required for its construction and deconstruction. A more true analysis of the overall environmental effects of the frame material would thereby be realised. However, this approach would require an investigator to identify two very similar buildings having similar floor area's and very similar specifications (other than in relation to the structural frame). This in itself is an intractable task, however, obtaining the necessary data (even allowing for the use of 'qualified guessing') to undertake complete LCA's for two ***complete*** buildings (one having a steel frame and one having a concrete frame) is considered highly impractical and it is probable that such an analysis could not be completed in any valid manner (there are simply too many sub- products, components, materials and processes and sub- processes involved with each, to synthesise).

Therefore, it is proposed that an alternative, more practical approach to analysing the environmental performance of the frame material is required in order that concrete frames may be compared with steel frames in an appropriate manner.

4.0 Proposed analysis method

It is proposed that the evaluation problem that has been described can be practically approached using a causal path analysis method.

The causal path method provides a robust analvtical framework within which the strength of influence betweeninterrelated variable&an be measured and understood. The method has been widely applied in the social sciences to investigate postulated cause and effect relationships and in this context it is considered to be appropriate to the task of analysing the causal relationships which exist between a technological decision, that is the selection of structural frame material, and the subsequent impact of that decision upon environmental criteria [3]. Path analysis is an analytical tool which provides for the quantitative investigation of postulated causal influences between a set of interdependent variables [4][5]. The method provides a framework within which appropriate regressors and predictors may be statistically analysed and the output of that analysis understood. Furthermore it allows the formulation of intuitive ideas concerning which of the causal influences are significant. A path model is typically specified as a system of simultaneous regression equations which are usually assumed to be linear, additive and recursive [6]. Path coefficients, the standardised partial regression coefficients, are calculated from the regression equations. These provide an indication of the relative importance of a given explanatory variable upon the response variables. The coefficient is usually described in the form, $p_{i,j}$, where the subscript, j, refers to the response variable and, i, refers to the regressor whose direct effect upon the response is measured.

Normally, the path coefficient, pi,j, explains the proportion of the standard deviation observed in the response variable, j, for which the regressor variable, i, is directly responsible. The residual path coefficient measures the proportion of the standard deviation of j which is explained by unmeasured extraneous variables.

Prerequisite to the construction of any path diagram is the assumption that the explanatory variables and the response variables can be placed in a causal ordering. It follows that changes in the value of any explanatory variable can effect variables later in the causal chain but cannot effect variables earlier in the chain. The causal ordering cannot be decided by empirical analysis of data; it must be determined from prior theoretical knowledge. *A priori* knowledge is the starting point from which path diagrams showing the manner in which variables are expected to relate to one another are developed. The *a priori* structure provides the framework for the statistical analysis of data and also for the interpretation of the results. During the analysis the hypothesised structure of interrelationships may be altered in response to the data, or alternative hypotheses may be tested against the data. It follows that the more realistic the *a priori* path diagram is to the true situation, the more meaningful will be the results of the path analysis. The fundamental task in applying the path analysis method is the construction of a path diagram which reflects as closely as possible the true situation.

5.0 Defining an appropriate causal path model

The first task in developing the causal path model involves clearly stating the objectives of the evaluation and understanding its purpose. The aim of the present study is to understand the environmental impact of steel and concrete frames in the context of contemporary building and construction projects. As mentioned earlier, the frame, despite having a relatively clear functional purpose, cannot be properly viewed as a usable product. The building itself is the usable product to which the frame contributes. This is important since a building project will clearly have a significant environmental impact whether or not a concrete or a steel frame is used to support it. In other words, if a building project is to be undertaken, an environmental consequence is inevitable. Therefore, what is important is not so much the environmental impact of the frame material itself but rather how significant the influence of the structural material is in determining the overall environmental impact of the building project. Subsequently it is of importance to understand whether or not changing the frame material will reduce the overall environmental impact of the building project in a statistically significant manner. Therefore, it is hypothesised that the overall environmental impact of a complete building project will be influenced to some degree by the frame material. The purpose of the path analysis is to test this hypothesis in order to understand whether or not the influence of the frame material upon the overall environmental impact of the building is *significant* and subsequently to understand whether or not the overall environmental impact of building projects can be reduced by alternative frame solutions; specifically in relation to steel frame techniques and concrete frame techniques, bearing in mind that both require the use (to varying degrees) of *both* materials.

In order to construct a provisional path diagram, it is necessary to consider the frame material as the explanatory variable and the environmental impact of the building project as the dependent variable. The diagram must then address how the influence of the frame material upon the overall environmental impact of the building project may be transmitted. In this case it is hypothesised that the frame material will contribute to the overall environmental impact of a building project in a direct manner and also in an indirect manner as a result of the many processes, products and components that are influenced in building projects as a result of the selected frame method. This introduces intervening variables to the path diagram.

Intervening variables are those through which explanatory variables may be expected to exert an indirect influence upon the response variable. The identification of such variables, of course, must be based upon *a priori* theoretical knowledge. In providing a framework which allows for both the analysis of explanatory variables and intervening variables, path analysis allows the quantification of both the direct and the indirect effects of the explanatory variables upon the response.

6.0 Specification of provisional causal path model

A path diagram to investigate the nature of the influence of the frame material upon the overall environmental impact of building and construction projects may be most simply specified as illustrated in Figure 2.

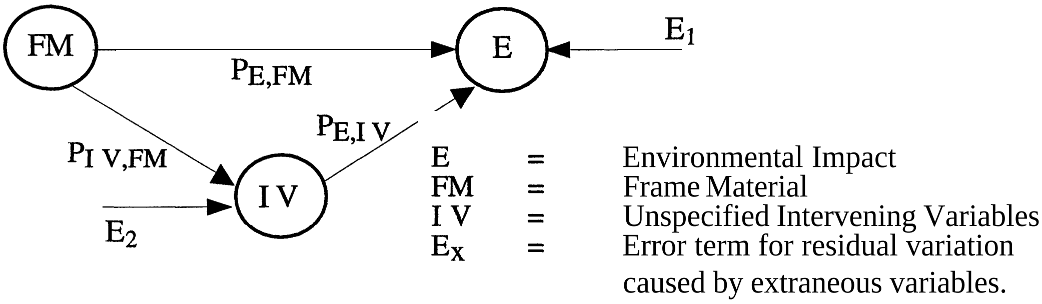
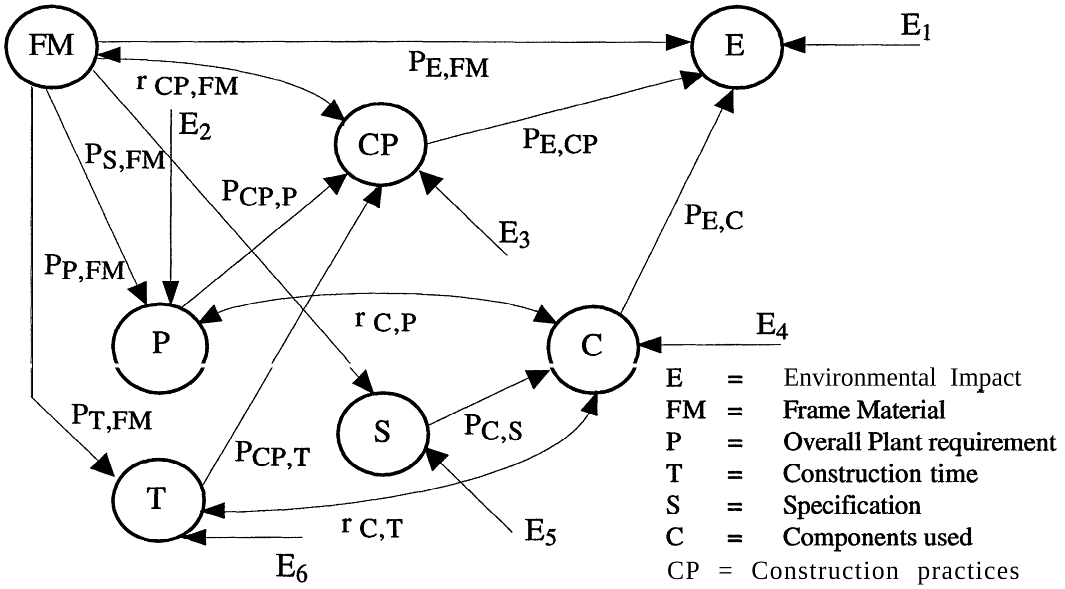


Figure 2 Simple causal path model to analyse influence of frame material upon the environmental impact of building projects.

Figure 2 illustrates that the frame material (FM) is hypothesised to have a direct influence upon the size of the overall environmental impact of building projects (E) and an indirect influence through a series of intervening variables. However, importantly, the inclusion of the error terms (El and E2) indicates that there are other variables which are excluded from the system of the model that are nevertheless believed to influence the value, E. Therefore the output of the model is an indication of the importance of the frame material in determining E *relative* to other factors which will inevitably contribute to E. As the research develops, a number of variables presently excluded from the model can be introduced to improve the explanatory power of the model.

The number of likely intervening variables is considered likely to be large. However, the more parsimonious the model, the more useful will be the results. In other words it is desirable to minimise the number of variables that are included within the provisional causal path model. Nevertheless, grouping all intervening variables together in the manner described in Figure 2 is both impractical (in terms of deriving a valid aggregate measure) and inappropriate in terms of understanding how the frame materials influence upon the overall environmental impact is transmitted. Therefore, the process of identifying appropriate groupings of intervening variables is presently ongoing. The aim is to produce a practical causal path model which realistically analyses the implications that the frame material selection has upon the building project process and product in order that the importance of the frame material in determining the overall environmental impact of building projects may be more appropriately understood.

As a result the simplified causal path model illustrated in Figure 2 above has been developed and expanded as described in Figure 3. Work is presently focused upon devising valid and practical measurement systems for each of the variables (particularly for the dependent variable, E) that have been incorporated within the provisional model.



Model Specification:-

$E = F\{P_{E,FM}FM + P_{E,CP}CP + P_{E,C}C + P_{E,E1}E1\}$

$CP = F\{P_{CP,P}P + P_{CP,T}T + P_{CP,E3}E3\}$

$P = F\{P_{P,FM}FM + P_{P,E2}E2\}$ $T = F\{P_{T,FM}FM + P_{T,E6}E6\}$

$S = F\{P_{S,FM}FM + P_{S,E5}E5\}$ $C = F\{P_{C,S}S + P_{C,E4}E4\}$

Total influence of FM upon E (I):-

$I = P_{E,FM} + \{P_{E,CP} \times P_{CP,P} \times P_{P,FM}\} + \{P_{E,C} \times P_{C,S} \times {}_{S,FM}\} + \{P_{E,CP} \times P_{CP,T} \times P_{T,FM}\}$

Figure 3 Proposed provisional causal path model

7.0 Conclusion

Approaching the evaluation of the impact of the frame material upon the environment in the conventional LCA manner of investigating the differing environmental impacts of two or more alternative products in relation to the delivery of equal amounts of a functional unit of production is considered to be unworkable and inappropriate. Therefore, a causal path model is under development to simplify the analysis problem. The output of this model will be a quantitative statement of the importance of the frame material in determining the overall environmental impact of building projects and an improved understanding of the differences between steel and concrete framed structures.

References

1. ENBRI. (1997) Concrete frames show the industry the way ahead, ***ENBRZ Newsletter,*** Issue 6, Spring 1997, BRE Garston, Watford.
2. Little, B. and Pederson, B. (1993) Planning a life cycle assessment. ***Environmental assessment of products,*** UETP-EEE, Helsinki.
3. Brown A W. and Allwinkle, S J. (1997), ***The influence of the frame material upon project** peformance*, Research report, British Steel Plc.
4. Little, R J A. (1979) ***Linear models and path analysis,*** Survey data; Report and selected papers, ST/ESCAP/89.
5. SWCS (1990), *Method **of path** coefficients: **A trademark of** Sewall **Wright,*** Madison USA.
6. Boyle, R P. (1970) Path analysis and ordinal data, ***American journal of sociology,*** Vo175, No 4.

The influence of finely ground ceramic waste materials on the properties of new mortars

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Abstract

The aim of this work is to analyze the influence that the addition of finely ground, hardened mortar and ceramic waste materials has on the properties of the mortars.

For this purpose, eight different mortars were produced using cement, ground waste material and natural sand.

The waste material used in this study was prepared in laboratory because of the difference in combinations frequently found between the two components when the waste is material collected at construction sites (hardened mortar and ceramic material).

The results obtained indicated that finely ground recycled waste materials are technically appropriate for use in mortar.

There is a large increase in the mechanical properties of mortars in function of the quantity of ceramic materials existing in their composition

Mortars that are produced with recycled materials present an economy of 30% in the use of cement, when compared with mortar produced with natural aggregates.

It is, however, important to carry out a complementary study to evaluate the behaviour and durability of this mortar as to time.

All the tests carried out according Brazilian standards.

KEY WORDS: Mortars, Waste material, Recycling

1 Introduction

Although building techniques and methods adopted in some regions of the country have evolved and the rendering of internal base plaster is widespread, the building process which utilizes internal and external rendering based in Portland cement, lime, clay, sand and other additions is still dominant in Brazil. Therefore, it is easy to see and comprehend that this building process will always generate an amount, no matter how small, of waste material that will not readily disappear .

The study was destined to contribute with data that will help in solving the problem of what to do with the large amounts of inorganic[1] material generated by civil construction by recycling it at the job site, in the production of mortars. This is particularly urgent as areas designated to receive this material are rare and the unlawful disposal of such material is prejudicial to the population and is an affront to environmental policies.

Therefore, in the SBTA I[2] an initial study has shown what influence the presence of finely ground waste material, such as ceramic blocks, concrete blocks and hardened mortars have on the performance of new mortars.

2 Objective

The results of the present study along with those of SBTA I, constitute part of a more comprehensive research whose objective is to determine in a technical fashion the influence that each component of the waste material has on the performance of mortars.

The researchers found it important for this study to detail the contribution of the pozzolanic activity of the ceramic waste in the properties of the mortars. This was due to results obtained which indicated an increase in resistance to the compression related to the addition of ceramic material.

Mixtures of finely crushed ceramic material and finely crushed hardened mortars were tried in different proportions and used as additions in the preparation of the new mortars which were then tested.

3 Methods and materials

For this study, four (4) mixtures of waste materials were prepared in the laboratory and each added to a mortar being tested. The study used two mix proportions resulting in eight (8) distinct mortars.

[1] The volume of construction waste material was about 2,000 ton/day just in the city of São Paulo. This volume of waste material from civil construction represent about 15% of the total amount of the urban nibbish estimated at about 12,000 ton/day [1].

[2] SBTA Brazilian Tecnological Symposium on Mortar

3.1 Materials

The materials used to elaborate this study were:

a) Medium sand, washed; used at our job sites to produce mortar.

b) Compost Portland Cement Type CP II-E- 32 equivalent to I (SM) ASTM C595.

c) Components present in the waste material:

c- 1) Ceramic blocks and clay bricks of different origin;

c-2) Mixed hardened mortars.

3.1.1 Collection and selection criteria

The materials were collected and ground at construction sites in the city of São Paulo.

Those sites used a rolling mill that not only recycled the waste generated at the site but also produced the mortars used at the job site.

The study made a separate collection of ceramic materials (classified as 1st quality and 2nd quality ceramic blocks and clay bricks) and mortar waste.

After a visual verification of the collected sample's homogeneity to avoid the presence of anything unwanted, the selected materials were ground in ANVI-500 type mills for about 30 (thirty) minutes at the sites. They were then in packed and transported to the drying process in the laboratory oven.

The criteria used to select the components of the waste for the experiment were:

Ceramic materials – only second quality ceramic blocks were chosen from the samples collected, because they presented the desired pozzolanicity[3] and also because they are currently the most widely used in the building processes in Brazil.

Mixed mortars – from different jobs sites were ground and mixed in a random way and then stored in the laboratory for more than 180 days to avoid the undesired influence of any finely ground cement that still not hydrated, could act as blending in the new mortar produced.

3.1.2 Characterization of the materials

The sieve analysis, as well as other physical characteristics, of the components used in the preparation of the recycled mortar used in this study is indicated in Table 1.

The components used in this experiment were ground for 30 min. They were then transported to the laboratory and stored for 180 days to avoid any undesired influence from parts of non-hydrated cement that after ground could act as blending in the newly produced mortar. Before being used the components were dried in oven at 105° C.

At the same time, Instituto de Pesquisas Tecnológicas IPT made a test to determine the pozzolanic activity of ceramic waste materials classified as 1st quality and 2nd quality ceramic blocks and clay bricks.

The chemical characteristics of the material used in preparing the waste as well as of the characteristics of the cement (CP II E-32) used in the preparation of the tested mortars are shown in the following, Table 2.

[3] Pozzolanic activity is the capacity of reaction of a given substance with CaO. in order that the pozzolanic activity presented by the substance is able to contribute with an increase in compression strength there must be a consumption of at least 330 mg of CaO / g of the sample in the Chapelle test. Only in this case can the material be considered as pozzolanic material[2].

Table 1 Physical characteristics of components used in the preparation of waste materials.

		Materials Cumulative Percentage Retained			
Characteristics	Standards	Ground ceramics	Ground mortar	Sand	Cement
Sieve size(mm)					
4,8	NBR 72 17/87	2	1	2	
2,4		4	12	4	
1,2		10	29	10	
0,6		25	44	35	
0,3		43	57	79	
0,15		66	73	97	
Pan		100	100	100	
Fineness Modulus		1,50	2,16	2,27	
Maxi. Size of Aggregate (mm)		2.40	4.80	2.40	
Materials in Powdered State (%)	NBR 72 18/87	30.4	15,4	-	
Organic Impurities (ppm)	NBR 7220/87	< 300	< 300	< 300	
Specific Gravity (kg/m³)	NBR9776/87; NBR 6474/84	2510	2520	2590	3120
Bulk Unit Weight (kg/m³)	NBR 725 1/82	1145	1377	1417	1130
Fineness (m²/kg)	NBR 7224/89	586,4	231,9		364,3

Table 2 Characteristics of cement and components used in preparation of waste materials

Characteristics and standards test	Cement	Ground ceramics	Ground mortar
Ignition loss (%) (NBR 08347/91)	3,1	2,5	7,0
Insoluble residue (%) (NBR 05744189)	5,2	99,2	83,2
Pozzolanic activity - Chapelle Method Test adapted[4] (mg of CaO/ mg of sample)			
Ceramic blocs 1ª quality	-	242	-
Ceramic blocs 2" quality *	-	454	-
Clav brick	-	565	-

* Material used for preparation of added (waste).

Table 3 shows unit weight in the loose state of the mortar samples prepared in laboratory.

Table 3 Unit weight of added (waste) prepared in laboratory.

Added	Unit weight in loose state (kg/m³)
c (100%)	1.145
Ca (66% ceramic : 34 % mortar)	1.222
cA (34% ceramic : 66% mortar)	1.300
A (100% mortar.)	1.378

3.1.3 Mix proportion of waste's components

The relative composition of mix proportion components was varied according to the proportions indicated in Table 4, while keeping the other variables of each mortar produced, constant. This was done to obtain a representative waste from the diverse stages of any given job.

[4] According test report IPT n. 829.785 de 14/set/95.

Table 4 Mix proportion additions by volume.

Manufacture added	Ceramic matermic material	Hardened mortar
C[5]	100%	0%
Ca	**66%**	**34%**
cA	**34%**	**66%**
A	**0%**	100%

3.2 Mortars

As a general rule, an effort was made to maintain the same characteristics of mortars used in jobs. To do this, the same mix proportion by volume as that normally used by construction companies was employed.

3.2.1 Mix proportion

In order to follow the rules set forth in item 3-2, the traces 1 3 : 8 and 1: 1.5: 6 in volume, were adopted. These were transformed into weight with the addition of the four (4) mixtures, previously prepared. The eight mortars indicated in Table 5 were produced.

Table 5 Relationship between mix proportion by volume and mass of test mortar.

Addition used for preparation of test mortar	Mix. Proportion by volume (Cement: Added: Send)	
	(1 : 3 : 8)	(1 : 1,5 : 6)
C	1 : 3,04: 10,290	1 : 1.520 : 7.715
Ca	**1 : 3.25: 10.290**	**1 : 1.623** . 7.715
cA	**1 : 3.45: 10.290**	**1 : 1.726 : 7.715**
A	**1 : 3.66: 10.290**	**1 :** 1.829 : 7.715

3.2.2 Molding of the specimens

A total of 264 specimens were molded. Ninety-six (96) cylinders of 50x 100 mm were used to determinate the compression strength; ninety-six (96) cylinders of 50x100 mm were used to determine the elastic modulus and seventy-two (72) prisms measuring 40x40xl60 mm were used to determine flexural strength.

3.2.3 Properties studied

The following properties were selected for investigation in this experiment:

a)For fresh mortar:

- *Unit weight*- was determined according to Brazilian standard NBR 7251/82 to permit to get the cement content employed in each mix proportion.
- *Water retention* - was determined in Biichner funnel in accordance with Brazilian standard NBR 9287/86, to evaluate the capacity, that finely ground ceramic material added to mortar has, in retaining molding water.
- *Content* of *cement*- was calculated by the equation $C_{(cement\ amount)} = \gamma_{Mortar} / M_{total}$
- *Flow* - the amount of water used was that necessary to get a flow of 3 10 ±10 mm as determined by the flow table according to Brazilian standard NBR 7215/81.

[5] According to the nomenclature adopted, the capital letter represents the material existent in a higher proportion in the mix, ceramic material or hardened mortar.

4.2.2 Content and flow

In the laboratory, during the preparation of mortar, a flow of 3 10 ± 10 was adopted. The mix proportions by weight of mortars, on average, are showed in Table 7.

Table 7 Mortar properties obtained from a flow of 3 10 ± 10 mm.

Mix. Proportion	1: 3: 8				1: 1,5: 6			
	C	Ca	cA	A	C	Ca	cA	A
Cement content (kg/m^3) (%)	109,0 (7,0)	107,5 (6,9)	105,0 (6,8)	103,1 (6,7)	157,9 (9,8)	156,0 (9,7)	152,0 9,6)	149,0 (9,5)
Waste content (m^3/m^3) (%)	0,289 (21,2)	0,283 (22,3)	0,279 (23,4)	0,270 (24,5)	0,209 (14,8)	0,207 (15,7)	0,202 (16,5)	0,197 (17,3)
Sand content (m^3/m^3) (%)	0,785 (71,8)	0,767 (70,8)	0,757 (69,8)	0,745 (68,8)	0,849 (75,4)	0,842 (74,6)	0,821 (73,9)	0,802 (73,2)
w/c Ratio	3,146	3,111	3,030	3,016	2,099	2,053	2,134	2,086
w/dry mat Ratio	0.219	0,214	0,206	0,203	0,219	0,199	0,204	0,198
Flow (mm)	305	311	312	308	322	325	335	330

4.2.3 Water retention

Figure 1 presents the different values of water retention for each one of the eight (8) mortars prepared. As can be seen, the best results were gotten by using waste material Ca, composed of 66% ceramic material and 34% hardened mortar. The values were slightly lower than those obtained by JOHN [5] which were 57% and 64% for conventional mortar (Cement : Lime : Sand) using a mix proportion volume 1:2:9 with a flow of about 300 mm dolomite lime and calcic lime.

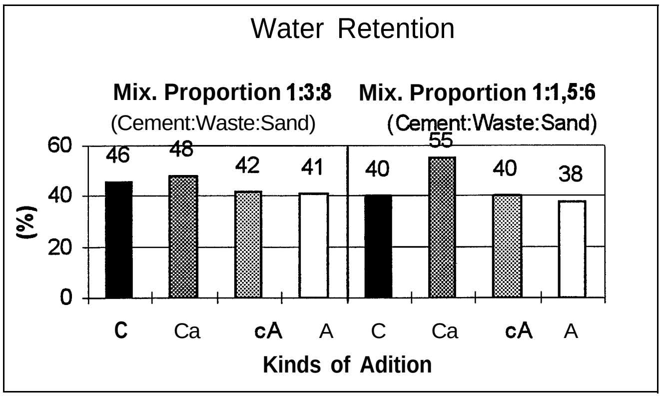

Figure 1 Variation of the water retention index

4.3 Results of hardened mortar.

4.3.1 Compressive and flexural strength

Figure 2 presents the values of compression strength after 7, 28 and 91 days according to the addition employed. Compressive strength increases by 2.5 times with a variation of cement content of no more than 5% and prepared with and without ceramic materials. This same tendency can also be observed for tensile strength as indicated in Figure 3

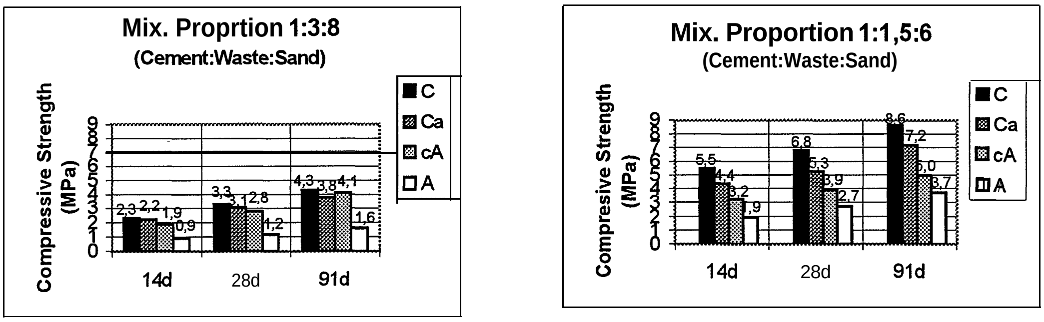

Figure 2 Compressive strength, mix proportion 1: 3 : 8 e 1: 1,5: 6

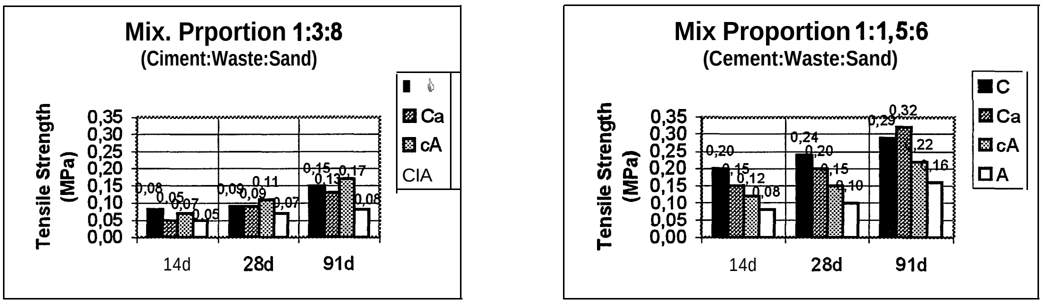

Figure 3 Tensile strength, mix proportion 1: 3 : 8 e 1: 1,5: 6

4.3.2 Elastic modulus

The normal values for mortars with a mix proportion of 1: 2: 9 were around 1 GPa at 28 days [5]. For those mortars with a mix proportion of 1:3 : 8 and produced with recycled material. the values at 28 davs were practically the same, who it is show in Figure 4 for some mortars tested.

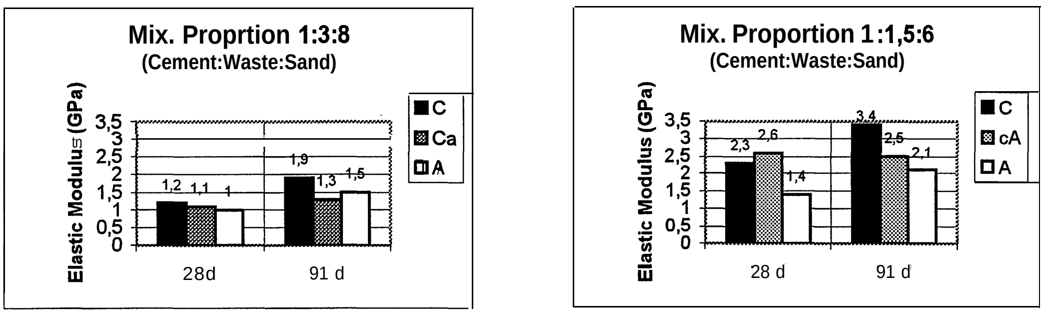

Figure 4 Elastic modulus evolution for mix. proportion 1: 3 : 8 e 1: 1,5: 6

5 Conclusions

The results have indicated that either a higher or lower amount of ceramic material or hardened mortar added to mixes, has an influence in its main proprieties.

Substituting with a higher proportion of one of the two waste materials presents a differentiated influence.

In general, a higher amount of ceramic material in the fresh mortar state, produced a mortar that is more compact (an increase in unit weight). At the same time, a higher presence of hardened mortar waste produces mortars that consume less cement, a difference of about (3 to 5%) as compared to mortars richer in ceramic waste materials.

A modest variation (3 to 5%) in the consumption of cement was detected for those mortars under study. This results in an increase of around 2,5 times in compression strength. This significant modification can be explained by the development of the binder potential of ceramic material present in the waste and due to a pozzolanic reaction with filler effect.

On the average, mortars produced with waste material present a reduction in cement consumption of about 30% when compared with data found in literature for similar mortars [6].

This work has shown that it is possible for studies and technological evaluations about recycling (not only of the materials tested here, but of many others for their low cost and immediate possibility of utilization) to change the value concept of what is called "waste", "refuse" and "debris", and in turn affect the laborious and precarious process toward their final destination.

6 References

1. PINTO, T.P.; *Entulho de construção: problema urbano que pode gerar soluções* São Paulo 1992. CONSTRUÇÃO PINI pll -12.
2. RAVERDI, M.; BRIVOT, F.; PAILLERRE, A.M.& DRON, R. *Appréciation de l' activité pouzzolanique des constituantes secondaires,* In. Congrès International de la Chimie des Ciments, 7e, Paris, 1980, vo 111, IV-36.
3. CINCOTTO, M. A.; KAUPATEZ, R. Z. *Seleção dos Materiais Quanto à Atividade Pozolânica*. IPT/DEd n.034 p.23-26 - 1988
4. HAMASSAKI, L. T; SBRIGHI N, *C;* & FLORINDO, M. *C. Construction Waste in Rendering Mortar* In: Concrete in the Service of ManKind - International Conference Concrete for Environment Enhancement and Protection, Dundee - jun. 1996. Proceedings. Ravindra & Thomas Grã Bretanha - 1996 p. 485-494
5. FIORITO, A.J. S.I. *Manual de argamassas e revestimentos: estudos e procedimentos de execução.* São Paulo PINI -1994
6. JOHN V; CINCOTTO, M.,A.; GUIMARÃES, J. E. P & RAGO F. Cal x Aditivos orgânicos *Téchne* n. 11, pag. 25a29. julho/agosto 94.

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Methodology to evaluate used foundry sand as concrete aggregate

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Abstract
Nowadays used foundry sand becomes, more and more, an environmental problem because it is not easy to find a safety way to dispose it. This is due to the fact that during some metallurgic processes many times, it can incorporate heavy metals contaminations and the use of organic compounds(as phenolic resins, for example) which can migrate in variable proportions to residual sand.
To verify the possibility of reusing foundry sand as concrete aggregate IPT(Technological Research Institute of São Paulo State-Brazil) developed a methodology with the following steps:
-(1) used foundry sand samples technological characterizations;
- (2) production of concrete specimens based in selected mix proportions;
-(3) performance tests including physical- properties and mechanical strength
-(4) stability and immobility of the contaminants(heavy metals and organic compounds) through Brazilian Standard Test(NBR- 10 004 Solid residues) which involves lixiviation and solubilization procedures.
An example of application of the suggested methodology is presented with its mechanical and chemical test results and conclusions about its applicability for similar materials.
Keywords: Waste materials, used foundry sand, inertization, evaluation methodology.

1 Introduction

The scarcity of good quality aggregates near mostly of great cities induces a big effort to research alternative sources necessary to improve urban growth and infrastructure construction. At same time environmental reason promote need for protecting nature against predatory exploitation, through maintenance of the current explored mines, in acceptable level of production.
One of these alternatives is recycling industrial waste with potential applicability in function of its physical/mechanical characteristics. The used foundry sands have a good shape, strength, but, sometimes, do not show chemical stability because some kinds of contaminants can exhibit a hazardous behavior. These contaminants are mainly heavy metals and organic resins as phenolic ones (acid or basic type).
This paper proposes a methodology to evaluate the applicability of used foundry sand through inertization process with portland cement paste as a cover material which makes a barrier for solubilization or lixiviation of dangerous substances.
Besides aspects of public health it is necessary to consider economic aspects because costs of used sand disposal are so high in Brazil – near US$ 20-25/ton and in certain conditions it can be over US$ 60/ton.
The inertization by a Portland cement shield makes possible, if reached production of masonry blocks, structural concrete and some kinds of rendering mortars with safety and adequate technological properties. It becomes only an optimization exercise for the proportioning of concrete materials components.

2 Methodology

2.1 Fundamental principles

The proposed methodology is founded on some steps: representative sampling; run mechanical and chemical tests to verify stability and immobility of dangerous contaminants of sand in concrete specimen prepared with a specified compressive strength (30 MPa) and an accurate data interpretation.
This method try to represent structural concrete mixed in current proportions and its behavior when lixiviation and solubilization are increased to extreme conditions.
For used foundry sands from metallurgic processes without heavy metal or phenolic resins the evaluation have less difficulties but an accurate verification is requested.

2.2 Sampling

Real use conditions must be reproduced for running valid tests. It is very important to verify the waste homogeneity and divide it in lots with the same main characteristics according to the necessary. In our case these conditions are not easy to reach because waste materials are normally neglected, so this is generally a new concept to introduce in the procedures of technical staff who manages the waste. This spends attention and has serious consequences in case of differences between test samples and materials, which are really used as aggregates. Grain size distributions, or needing for milling, for example, are characteristics that influence utilization methods and concrete performance.
Each situation requires an analysis to define adequate sampling procedures.

2.3 Waste characterization

A previous characterization of wastes is made at the beginning of study, with a petrographic examination and X-ray fluorescence analysis, and eventually Chromatography or Infrared Spectroscopy if organic compounds are expected.

2.4 Mechanical performance concrete tests

Since concrete for masonry and pavement blocks is made using vibrating and compression, with demolding in the fresh state, cohesion and workability are important in this condition, and influence concrete properties after hardening. To simulate a concrete block-molding machine the specimens for tests are vibrated and pressed into standard conditions using an adapted device from a "VeBe" apparatus currently used for measuring dry concrete consistency.

Specimens are cylinders with 7.5 cm, diameter and 15 cm, height, , molded with a standard compression with a standard vibrating time. After humid chamber curing (relative humidity > 90%, temperature 22±2 °C) of 3, 7, or 28 days, specimens are tested in compressive strength by NBR 5739/9 ABNT method.

Compressive strength is the most important property of concrete, since it is not only a mechanical performance index, but it also is related with durability, impermeability, water absorption, etc. If there is some perturbation in hydration due to the residue, it is possible to detect it by observing perturbations on compressive strength-time relationship.

2.5 Standard concrete proportioning

The above test results permit to construct graphics relating compressive strength with concrete proportions. The interpolation in these graphics makes it possible to reach a concrete mixture proportion with. expected standard strength (e.g. 30 MPa, adopted in this study). The intention is to make standard mechanical performance concrete to be compared with other concretes with similar mechanical performance using the following tests.

When standard concrete is approved, graphics are also useful for concrete proportioning and cost analysis.

2.6 Stability and immobility tests on standard concrete

Standard mechanical performance concrete is previous and sufficiently ground for complete passing in the 9.5 mm sieve; ground sample is submitted to NBR 10005/87 and 10006/87 ABNT -procedures for, respectively, residue lixiviation, and solubilization. These procedures are standard simulations of weathering agents over pulverized concrete after, for instance, a building demolition in which residues were present as a part of the material.

Tolerances for some chemicals are shown in Table 1.

	Maximum limits (ppm) for	
Determination	Solubilization residue	Lixiviation residue
As	0.05	5
Ba	1	100
Cd	0.005	0.5
Pb	0.05	5
Cr	0.05	5
Hg	0.001	0.1
Ag	0.05	5
Se	0.01	1
Al	0.2	
CU	1	
Fe	0.3	
Mn	0.1	
Na	200	
Zn	5	
Phenol	0.001	-

Table 1 Tolerances for solubilization and lixiviation residues

3 Practical examples

Two residue tests are presented as examples:
A residual sand originated by "Block Foundry" metallurgical process and other called "Ecolotec", with phenolic resin addition during industrial procedures, both used in manufacturing of cast components for automotive industry in São Paulo, Brazil.
A petrographic analysis showed two rounded grain sands with polished surface texture, where quartz is practically the only mineral specimen. X-ray fluorescence analysis showed no traces of Fe, Al, Na, and Mg, thus those were not quantified by specific tests.
"Block Foundry" residue presented Fineness Modulus 1.49, and "Ecolotec" residue, 1.85, according to NBR 7211 ABNT.
Cement of Brazilian type CP II-E 32 (Composed Portland Cement with less than 34% Blast Furnace Slag Addition) was used, with Blaine Fineness 353 m^2/kg and Standard Compressive Strength 38.2 MPa according to methods cited by Brazilian ABNT NBR 11578. As coarse aggregate a 9.5 mm maximum size crushed granite with 5.44 Fineness Modulus according to NBR 72 11 ABNT was used.
Experimental mixture proportions were made with the above materials, discriminated in table 2, using principles for designing concretes for masonry blocks (Tango, 1994).

Concrete mixture proportions (cement : fine aggregate : coarse aggregate, weight)		
Mixture proportion	"Foundry Block" sand residue	"Ecolotec" sand residue
"Poor"	1.00:2.82:5.18	1.00:3.11::4.89
"Medium"	1.00:1.89:4.11	1.00:2.08:3.92
"Rich"	1.00:0.96:3.04	1.00:2.05:2.95

Table 2 Experimental Concrete Mixture Proportions for Compressive Strength Tests

Compressive strength test results for the above concretes are graphically and analytically related with total aggregate cement proportions in figures 1 and 2.

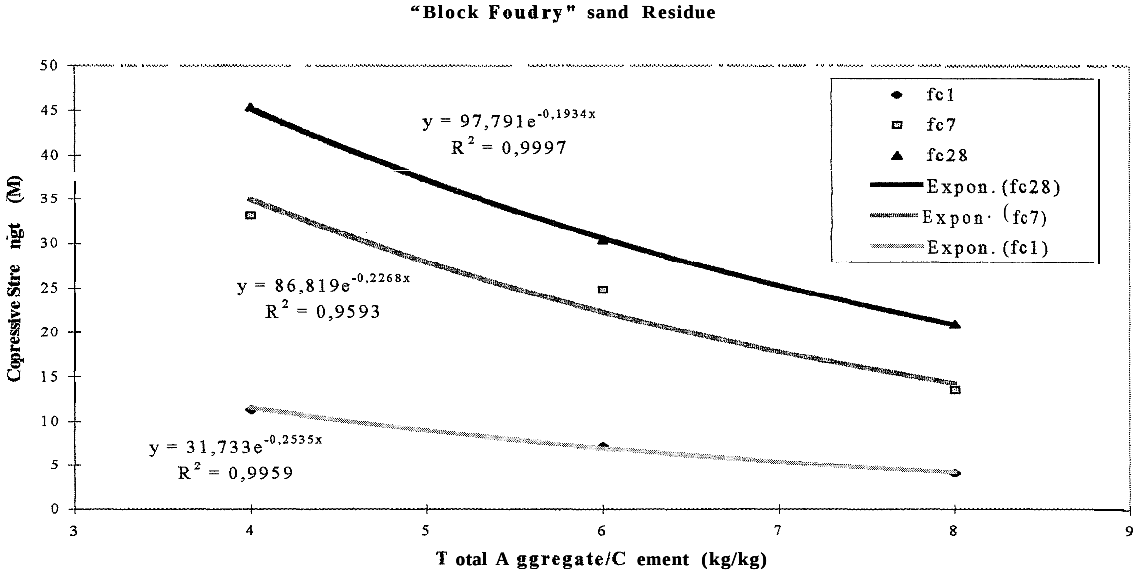

Figure 1 Aggregate-cement ratio versus compressive strength for concretes made with "Foundry Block" sand residue as fine aggregate. f_{c1}, f_{c7} and f_{c28} are compressive strengths at 1, 7 and 28 days..

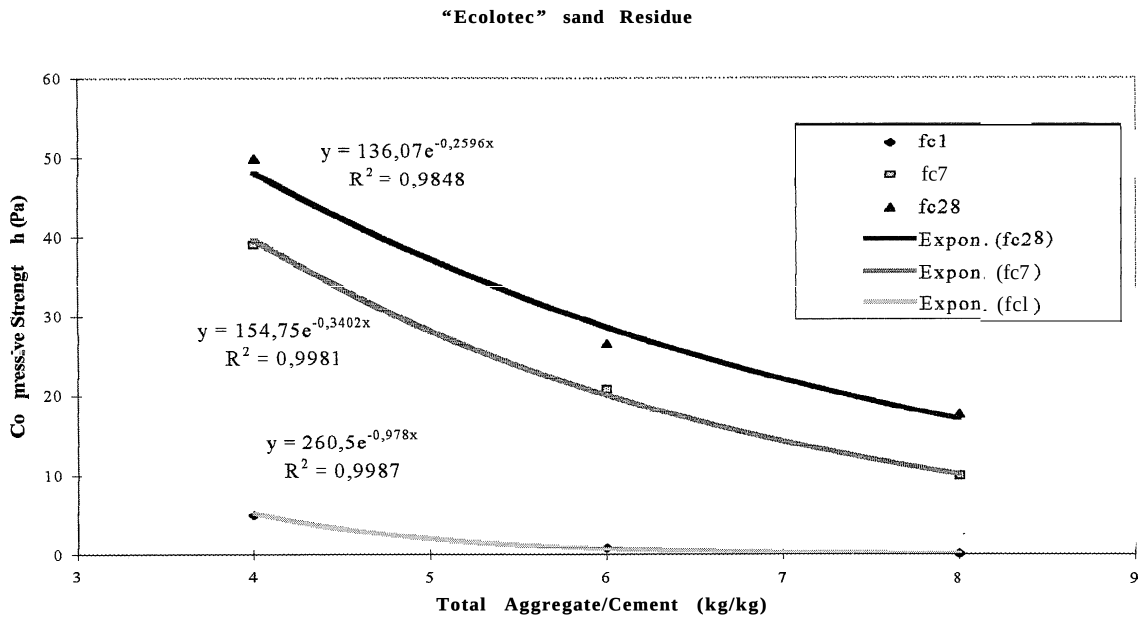

Figure 2 Aggregate-cement ratio versus compressive strength for concretes made with "Ecolotec" sand residue as fine aggregate. . f_{c1}, f_{c7} and f_{c28} are compressive strengths at 1, 7 and 28 days.

With the equations for 28 days shown in figures 1 and 2, and imposing the original concrete fineness modulus, it was possible to calculate the ideal mixture proportions for obtaining the standard compressive strength 30 MPa. The calculated mixture proportions were (cement : fine aggregate or residue : coarse aggregate):

1 .OO: 1.99:4.22 for "Foundry Block" sand residue;

1.00: 1.98:3.84 for "Ecolotec" sand residue.

With these standard mixture proportions, specimens were molded, moist cured up to 28 day age and ground passing 9.5 mm sieve for lixiviation and solubilization tests, which results are in table 3.

Determination	“Foundry Block” sand residue		“Ecolotec” sand residue	
	Solubilization	Lixiviation	Solubilization	Lixiviation
As	<0.002	0.002	<0.002	<0.002
Ba	1.0	0.7	1.3	0.9
Cd	<0.001	<0.05	<0.001	<0.05
Pb	<0.05	<0.5	<0.05	<0.5
Cr	<0.05	<0.5	<0.05	<0.5
Hg	<0.0001	<0.0001	<0.0001	<0.0001
Ag	<0.05	<0.05	<0.05	<0.05
Se	<0.002	<0.002	<0.002	<0.002
Al	-	-	-	
Cu	<0.1	-	<0.1	
Fe	-	-	-	
Mn	-	-	-	
Na	-	-	-	
Zn	<0.1	-	<0.1	
Phenol	0.001	<0.063	0.145	0.452

Table 3 Test results for Solubilization and Lixiviation Atomic absorption method, except Phenol, by colorimetry.

4 Discussion

Figures 1 and 2 show that there are differences between strength gains with time in concretes with “Block Foundry” and “Ecolotec” sand residues. The presence of phenol is the main difference between these concretes, probably the cause of strength retarding in 1 day age, with better relative strengths at later ages, for "Ecolotec" sand residue. Similar effect on strength is shown by other organic impurities, as sugar, into Portland cement concrete. Another possibility is an eventual degradation of phenolic compounds in cement paste alkaline environment during time, which would induce the lowering of retarding effect.

In table 3, comparing its results with table 1, it is easy to see that “Ecolotec” sand residue is not acceptable because of Ba and Phenol levels.

Therefore, chemical results in table 3 are affected by components originated not only by the used residues, but also by cement, coarse aggregate and water. Thus, it is important to compare these results with those from concrete made with original sand without metallurgical process influences. This was suggested for continuing the studies.

Some determinations as Al, Fe, Mg, Ba, and Na are in a very low level and can be strongly affected by portland cement chemical composition, and the limit standards for those and other elements maybe would be object of more discussion.

5 Conclusions

This methodology was applied to study several samples originated by many kinds of metallurgic process and ever showed a good applicability and sensibility to distinguish between dangerous and applicable ones.
The main proposition of this paper is to establish a standard level for compressive strength of concrete specimens, and in this manner to have a correspondence with structural requirements for concrete
Improvements in the methodology, for the next steps research in this field, would be summarized in three basic ideas:
To introduce previous characterization of original sand (without any use or metallurgic process influence);
To study the possibility for using monolithic or not completely ground samples;
To introduce tests for durability of reinforced concrete, including atmospheric carbonation, chloride permeability and others.

6 Acknowledgements

To chemical trainee Marco Mattaveli, for solubility and lixiviation tests.

7 Reference

Tango, C.E.S. (1994). Mixture Proportioning Fundaments for Structural Masonry Concrete Blocks [Fundamentos da Dosagem de Concreto para Blocos Estruturais]. 5th. International Seminar on Structural Masonry for Developing Countries. Santa Catarina University, University of Edinburgh, ANTAC, Florianópolis, Brazil, 2 1-24 Aug., Proceedings, pp. 2 1-30. In Portuguese.

Efficient Hydrophobation of Concrete with Novel Silicone Products

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Abstract

The presented class of products is an important addition to the existing variety of silicone based formulations for use in building protection. Compared to most silicone masonry water repellents marketed so far – which are usually applied as liquid formulations – this new protection system has a higher viscosity.

The novel product line shows significant innovative features:

- *easy application* with airless spraying equipment or other means
- *„ over-head " application possible* (no dropping of product)
- *better working efficiency* by achieving a high impregnation depth with a one-step-application because of possible higher film thickness
- *optimum distribution of the product* on the construction material by achieving a constant film thickness – and thus constant quality of the impregnation
- *optimum control overpenetration depth* (product absorption) by adjusting the film thickness (> 5 mm penetration at up to 300 g/m^2)
- *no loss of active material* due to evaporation or low viscosity on vertical sites, thus providing minimization of environmental pollution
- much *higher content of active silicones* compared to regular emulsions
- *high penetration depth* better than pure silane compositions by longer contact time

Because of the combination of above mentioned product specifications this novel product is highly recommendable for water repellent treatment of construction materials, especially concrete. It was possible to verify the lab data by field trials on selected concrete structures.
These results as well as the hydrophobing effects and application methods of the above mentioned product line – as well as a general introduction into silicone masonry water repellents – will be dealt with in the presentation.

Keywords:
Concrete Protection, Creme, Hydrophobation, Silanes, Silicones, Siloxanes, Masonry Water Repellents

1. Introduction

One of the main physical properties of silicones is their pronounced water repellent effect on treated substrates. So shortly after industrial production had started some decades ago, silicones were used as impregnating agents, e.g. for textiles or building materials.

Today a variety of customized silicone products is used to protect buildings and building materials against moisture and subsequent physical, chemical, and biological deterioration. During the years, the change in building materials used, tougher performance requirements, and greatly enhanced environmental awareness were some of the driving forces for continous innovation in the field of silicone masonry water repellents.

One of the changes in product formulation which is still going on is the tendency to use water based rather than solvent based products. One further step will be a change of physical state. Up to now, ready-to-use silicone based masonry water repellents have always been liquid, now a new generation of pasty and solid products is being developed.

The use of pasty agents is especially interesting for protection of concrete structures, where a very dense material of relatively low water absorption is to be treated and a sufficient contact time is often not reached by using liquid products.

2. The importance of surface treatment in concrete protection

Reinforced concrete for many years had the image of a non-corroding, maintenance-free building material that was said to have a lifetime of some centuries. With such a common belief it was out of question why surface protection should be sensible – it was not. The disillusionment came in the 70s, when corrosion of many of the reinforced concrete structures became a public issue.

Damage of reinforced concrete is mainly caused by diffusion of carbondioxide into the concrete and subsequent carbonation of the containing lime, as well as absorption of pollutants like chloride ions. A crucial role in deterioration plays the penetration of water into the concrete by which the speed of corrosion is multiplied. The following points have to be considered:

- Preventive protection of non-corroded concrete
- Establishment of a lasting corrosion protection
- Protection of new concrete replacing old, deteriorated concrete
- Increase of chemical and mechanical resistance of the concrete mixture

A simple classification of surface protection systems, which is technically sensible as well, is the classification by thickness of the protecting layer:

- hydrophobing impregnation, which has no measurable “thickness”
  – water repellent + (if needed) oil repellent and/or strengthening
- socalled “sealings” (about 50 µm thick), which can not fill pores totally
  – strengthening effect and partly clogging of pores
- filmforming coatings (some 100 µm thick)
  – clogging of pores, CO_2-diffusion hindered, reduction of water uptake

3. Molecular basis of silicone masonry water repellents

Most of today's silicone masonry water repellents are based on polymeric silicone resins as the basic chemical structure. Since the monomeric silane building blocks to these resins are trifunctional alkyltrialkoxysilanes $RSi(OR')_3$, the resulting resin can be considered as an organomodified quartz ($RSiO_{3/2}$ instead of $SiO_{4/2}$). Thereby the water repelling effect is caused by the hydrophobicity of the alkyl group R.

Because quartz – or more general silicate – is the binder of most natural and artificial stones and masonry, the resemblance between silicone resins and quartz is the reason why silicone resins are so suitable to be used on building substrates, particularly in terms of durability and service life.

Silicone masonry water repellents, in contrast to filmforming organic polymers, do not seal the surface pores of masonry. They only modify the pores of the substrate in such a way that liquid water absorption is suppressed, while the pores remain open and water vapour permeability is not affected. Chemically spoken, covalent Si-0-Si bonds are formed between the SiOH groups of the substrate pores and the SiOR of the silicone, thus rendering the pores water repellent but leaving them water vapour permeable.

In the beginning of silicone masonry water repellents, solutions of polymeric methylsilicone resins in aromatic solvents were used. Since fully cured resins of high molecular weight are not soluble any more, lower molecular weight precursors have been used for that purpose.

On many low porous substrates like concrete, the penetration depth of silicone resin solutions or their precursors is not sufficient to meet current performance requirements. On these substrates the silicone resins have to be replaced by agents with even lower molecular weight, which are monomeric alkyltrialkoxysilanes or oligomeric alkylalkoxysiloxanes $R_xSi_x(OR')_y$.

After application to the masonry structure, all the mentioned agents will react with water or humidity to the cured silicone resins, which are anchored to the substrate by stable covalent Si-O-Si bonds while alcohol is liberated as by-product.

Modern silicone masonry water repellents are preferably mixtures of alkylalkoxysilanes and oligomeric siloxanes. The alkoxy groups OR' are either methoxy or ethoxy groups. The organic groups R are methyl or longer chain hydrocarbon substituents like octyl groups. Long chain substituents impart alkaline stability to the hydrophobing agents, since thermodynamical and kinetical effects prohibit decomposition of the cured resins by alkaline chemicals or substrates.

Until the mid 80s, silicone masonry water repellents were mainly used as solutions in organic solvents. There were only two exceptions: undiluted 100% products and water based siliconates – both for special applications.

Since solvents only act as a transport medium, after having fulfilled this function, they are simply emitted into the atmosphere. For this reason and due to increased public awareness in terms of ecology and health, there is only one implication for masonry water repellents as well as for paints:

Replace organic solvents by water wherever possible!

4. Aqueous silicone masonry water repellents

Besides the siliconate approach mentioned above which is by now well known for almost 40 years, basically there are two ways of dissolving and dispersing organosilicone substances in water:

- Producing silicone emulsions
- Introducing hydrophilic functional groups into polysiloxanes to get selfemulsifying systems

These two modern approaches to water based masonry water repellents will now be delt with in more detail.

4.1 Emulsion approach

Silicone emulsions for masonry protection have been used successfully in mainly three application:

- Silicone resin emulsions as binders in silicone resin emulsion paint
- Emulsions of special linear polysiloxanes as additives in masonry paints
- Emulsions of low molecular alkylalkoxysilanes and -siloxanes as penetrating water repellents and primers

4.1.1 Silicone resin emulsion paint

Silicone resin emulsion paint is regarded as the most modern of currently available facade coating systems [1]. Coatings with silicone resin emulsion paint are water vapour permeable like mineral paints but at the same time are also water repellent like filmforming dispersion paints. These unique properties result from the main binder component, an emulsion of a solid silicone resin. Since solid products can hardly be emulsified, the silicone resin either has to be dissolved in organic solvents or the emulsifying process has to be done with a liquid precursor of the – finally solid – resin. Of course, the solvent-free approach is more desirable due to ecological factors.

4.1.2 Silicone additives

Silicone additives are added to coating materials, mineral paints, dispersion paints, plasters, etc. in small quantities in order to change the coating's properties permanently – especially to improve water resistance while obtaining high water vapour permeability. Modern additives are solvent-free emulsions of functional reactive polysiloxanes. The following chemical structure is an example of such a high-performance siloxane:

$$H_2N(CH_2)_2NH(CH_2)_3Si(OCH_3)_2O[Si(CH_3)_2O]_nSi(OCH_3)_2(CH_2)_3NH(CH_2)_2NH_2$$

In many cases only 1% of the additive is required to reduce the water uptake by more than 90%, e.g. from 5 kg/m² down to 0.5 kg/m² (after 24h).

4.1.3 Masonry water repellents

For a long time it was thought impossible to create storage stable water based masonry water repellents. One of the main demands for masonry water repellents is that they have to be well penetating into the stone. If other parameters are kept constant, the penetration of a liquid into a building material is better when the viscosity is lower. In contrast to homogenous solvent based products where the viscosity of the whole solution is relevant, in emulsions only the viscosity of the oil phase – i.e. the silicone – is important [2]. Of course, to get good penetration results, low molecular weight alkylalkoxysilanes and -siloxanes have to be chosen. The problem, however, is that these agents hydrolyze and polymerize in water, thereby forming larger and larger molecules up to solid silicone resins. Consequently their penetration behaviour turns worse and worse with time.

In the mid 80s it was found that the hydrolysation speed of alkoxysilanes can be slowed down if silanes $RSi(OR')_3$ with longer chain organic substituents R (e.g. octyl or isooctyl) are used. The same effect results of the use of ethoxy instead of methoxy substituents as groups OR‘ [3]. Emulsions made of the mentioned silanes are storage stable for several months. Their main disadvantage is that the formation of the final water repellent polysiloxane in the masonry structure takes a rather long time. This problem could be solved by formulating an emulsion containing not only silane but also oligomeric and polymeric siloxanes [4].

Similar to solvent based products, such emulsions are:

- Storage stable over more than one year (before and after dilution)
- Well penetrating into mineral substrates
- Stable against alkalinity
- Suitable for all mineral substrates, concrete as well as natural stone

4.2 Selfemulsifying microemulsion approach

The storage stability problems with water sensitive alkylalkoxysilanes and -siloxanes when brought into contact with water via emulsifying were the reason for another development. Some years ago, Wacker-Chemie GmbH introduced a technology of water based silicone masonry water repellents – the so-called Silicone Microemulsion Concentrates – abbreviated and registered as WACKER SMK® technology [5].

Silicone Microemulsion Concentrates in terms of WACKER SMK® are low viscous, clear, anhydrous, and solvent-free liquids based on alkylalkoxysilanes and -siloxanes which – simply upon being poured into water – spontaneously form extremely fine particle (1 O-80 nm) silicone microemulsions.

It is well known that microemulsions of so small particle size require 10 times more emulsifier than common emulsions with particle sizes of 500-1000 nm, In addition, a co-emulsifier is necessary to achieve microemulsions.

Following this thought, conventional emulsifiers are unsuitable for use in masonry water repellent microemulsions because emulsifiers in the high amounts necessary prevent the development of the desired water repellency.

The concept behind silicone microemulsions of WACKER SMK® is therefore that emulsifier and coemulsifier are at the same time active ingredients and lose their emulsifying activity after being used.

WACKER SMK®s are diluted to form microemulsions by simply being poured into water. This should be done directly before application to the substrate since contact with water causes the reactive components to begin reacting within the microemulsion droplets. After activation, the silicone microemulsions gradually lose their effectiveness, e.g. their ability to penetrate into dense building materials.

Main advantages of the WACKER SMK® technology are:

- Solvent free products of 100% active ingredients
- Storage stability of the concentrates over years
- Easy to use
- Concentrated form (lower storage, transport, packing costs, and duty)
- Environmentally friendly (diluted with water)

Table 1 shows a comparison of performance between a solvent based allround impregnant (WACKER 290), a WACKER SMK® type product (WACKER SMK® 13 1 1), and a silane/siloxane emulsion (WACKER BS 1001) as described in the preceeding chapter. All products were used in a concentration of 10% actives on three substrates: lime sandstone, brick, and concrete.

It can be concluded that there are some differences in performance between the three product types, but all penetrate well into the substrate and reduce the capillary water absorption sufficiently.

Product	Substrate	Impregnant uptake [g/m²]	Penetration depth [mm]	Water uptake 24 h [g/m²]
	Lime sandstone	0	0	2.6
Untreated	Brick	0	0	5.0
	Concrete	0	0	1.2
	Lime sandstone	550	6-9	0.16
WACKER 290	Brick	2185	> 35	0.04
	Concrete	210	2-4	0.15
	Lime sandstone	540	5-8	0.18
WACKER SMK 13 11	Brick	1654	> 35	0.11
	Concrete	150	1-2	0.24
	Lime sandstone	530	4-6	0.19
WACKER BS 1001	Brick	1020	> 35	0.59
	Concrete	167	2-3	0.22

Table 1: Performance of solvent diluted (WACKER 290), emulsion (WACKER BS 100 1) and microemulsion based (WACKER SMK® 13 11) masonry water repellent.

5. Novel pasty silicone masonry water repellents

Silicone based water repellents in the past have always been liquids. The disadvantage of liquids is that excess material is running down at vertical surfaces and subsequently penetrating into the ground, thereby polluting the environment.

Another point is safety reasons, e.g. if the water repellent agent has to be applied by flooding „over head“, the applicator can hardly avoid to be contaminated with chemical substances (solvents plus actives).

Most interesting in these terms is the impregnation of reinforced concrete, particularly road constructions and bridges. In the past undiluted alkylalkoxysilanes $RSi(OR')_3$ were often used for this purpose. Since high performance concrete is a rather dense substrate, only highly concentrated (up to undiluted) and low viscous products penetrate sufficiently. Once chosen, even these products have to be applied at least two times in order to achieve a penetration depth of some millimeters and a coverage rate of at least 100 g/m^2. In addition, monomeric undiluted silanes are the most volatile of all silicone products and so lots of active material is lost by evaporation into the atmosphere [6].

Therefore the challenge was to develop a product line with the following characteristics:

- Excellent penetration even into high grade concrete
- Only one application step to obtain a sufficient coverage rate
- No volatility problems
- Good beading effect
- Water based and solvent free

These reqirements could be met by changing the physical state of the silicone masonry water repellents from liquid to pasty.

The first attempt to realize this was to combine silanes or siloxanes with thickening agents as bentonite or montmorillonite [7]. A main disadvantage of such products is that the thickener remains on the surface, thereby affecting the appearance and having to be removed later. Another drawback is the fact that the volatility problems with such a product are even worse than with the pure silanes because the agent is applied in a thick layer and the volatile components have plenty of time to evaporate instead of penetrating into the concrete.

Very recently pasty products have been developed which are not subject to these disadvantages. Their formulation principle is totally different from those mentioned above. Their pasty consistency is not achieved by using a thickening agent, it is achieved by a special emulsification process which is stopped at the stage of a high viscous phase and renders a storage stable product. As silicone active ingredients preferably mixtures of alkylalkoxysilanes and -siloxanes are used. By variation of the silane: siloxane ratio „tailor-made“ impregnants for different substrates can be formulated. The actives content normally ranges above 80% while the rest of the product is water.

These products are preferably applied via spraying with a modified airless equipment. This way, very easily layers up to 0.5 mm thickness can be achieved without loosing any material on vertical substrates. Witin a few hours the silicone penetrates complety leaving no visible remainings on the surface.

For demonstrating the performance of the new pasty products, a formulation was chosen which contained 80% actives and a silane/siloxane ratio of 9:1 (WACKER BS 69001). Concrete cubes (grade B35, 10 cm edge length) were covered horizontally with a 0.4 respectively 0.8 mm layer of WACKER BS 69001.

For comparison, well established liquid products were tested which were applied on to the concrete cubes by 5 minutes immersion (coverage rate approx. 100 g/m^2). All treated cubes were stored at ambient conditions for 2 weeks, immersed in water for 7 days, and then the water uptake was determined.

From the experiment's results it could be concluded that the pasty product penetrates tremendously well (at 0.8 mm layer 3 times better than the 100% silane) and at the same time is the only product in the test series which reduces the water uptake over 7 days by more than 90%. The penetration of the diluted products – especially the silane emulsions -- is extremely poor compared to the performance of WACKER BS 69001. As a consequence the water uptake reduction of these products is significantly lower.

Although water beading is sometimes considered as an „eye catch effect" (which might be true to some extent), a lack of beading effect is usually correlated with a lack of water repellency. For that reason water beading is important, even on concrete structures. In the formulation of the pasty product this fact was taken into account by chosing a silane/siloxane mixture as active ingredient and not a pure silane. Therefore, in contrast to pure silanes which evaporate from the surface near area, WACKER BS 69001 provides good water beading as soon as the emulsifier residues on the top of the surface are washed out.

6. Summary and prospect

Although it may sound a bit strange, several ways have been developed in order to formulate *water* sensitive *water* repellents into *water*. Meanwhile silicone emulsions and microemulsions are available for almost all applications where some years ago exclusively solvent diluted products were used.

Sometimes not only organic solvents but also active ingredients have to be considered as a problem in terms of ecology and health. An example are the undiluted, volatile alkylalkoxysilanes which are currently used for concrete protection. Due to their volatility, not neglectible amounts of these chemicals are emitted to the atmosphere during application.

In order to offer an alternative, pasty products were developed that penetrate into concrete orders of magnitude better than silanes. As water based formulations, these solid-free pastes – or cremes, as they are sometimes called – are much more acceptable regarding environment nd health.

This latest development is a good example that even the physical state of well established products is not invariable. The future of silicone based water repellents will be full of suspense – won't it?

REFERENCES

1. E. Bagda, Die *Mappe* (1990) no. 1p, 2 and no. 3p.**23.**
2. U. Demlehner, *Farbe + Lack 95* (1989) 708.
3. M. E. Wilson et al., *U.S. Patent* **829530** (filed 14.2.1986)
4. H. Mayer et al., *DE Patent AZ* **195 117 346.5** (filed 11.51995)
5. H. Mayer et al., *U.S. Patent 4661551* (filed 16.10.1985)
6. M.C. Simkins, *Clwyd County Council Report No.* **93336 (27.8.1993)**
7. E.F. Karlson, *Swedish patent 9400952-9* (filed 22.3.1994)

Life cycle assessment for the evaluation of environmental impacts of construction materials

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Abstract

The general focus on environmental aspects of human activities has triggered a growing environmental awareness in the building industry. Life Cycle Assessment (LCA) is a tool for the actors on the market to address the environmental dimension.

This report refers to a series of LCA-studies on building materials and components with the focus on concrete that have been undertaken 1994-97 within a project initiated by the Nordic Cement industry. (Environmental adaptation of concrete)

Emissions to air and water and use of raw materials and energy have been inventoried from the extraction of raw materials, over building process and user phase to the destruction of the building and final disposal of materials.

The inventory results have been evaluated with three different evaluation models.

A computer model has been developed and introduced to enable the use of LCA in day to day planning of environmental process improvement and product development.

The conclusions of the study from a methodological point of view;

- LCA is an adequate tool to map environmental effects of building materials.
- The inventory phase (LCI) provides a good base for the product environmental information that is being increasingly requested by the market.
- The evaluation models should be selected carefully and need some further elaboration to match the specific conditions applying to buildings regarding e.g. a long life cycle.

The conclusion from the specific case studies;

- High quality data on the environmental aspects of the production of cement and concrete have been provided.
- The differences with regard to environmental characteristics between construction materials, when only production phase is considered, 'Cradle to gate', is small and in many cases insignificant as compared to the user-phase.
- For products or materials with long expected lift-time the focus should be put on the user-phase performance. The user-phase usually accounts for over 80 % of the environmental loads. Careful urban development is a key factor for sustainability.
- For 'Green procurement' of buildings concrete is a good choice regarding components with long expected lifetime for example building frames, civil engineering works etc., were features like low need of maintenance or high heat-capacity in houses are essential. Shorter life cycles of enhances production and recycling aspects.

Keywords: LCA, Life Cycle Assessment, Sustainable buildings

1 Introduction

Within the Nordic project 'Environmental adaptation of Concrete', initiated by the Nordic cement industry, an LCA calculation model has been developed which has been used in several product studies.
The project has been financed by the cement industry in Finland, Norway and Sweden, TEKES in Finland and the Nordic Industrial Fund.
Different expert teams within the LCA field have been involved; Stiftelsen Östfoldsforskning, Norway, Chalmers Industriteknik and Chalmers Technical University, department of Technical Environmental Planning, Sweden and VTT, Finland.

This report gives an overview of the different studies that has been conducted so far.

2 Scope

The scope of the product studies has been to
- make an adoption of the general LCA-computer model on the specific product to be used in sustainable product development,
- get a rough comparison on environmental performance with alternative materials (Benchmarking) and to
- develop a base for environmental product information.

Aspects like work environment and indoor health are not included in this study as there are not any scientific models available to connect such parameters with the exterior environmental aspects normaly dealt with in LCA.

3 Methods

The inventory and evaluation of data and the adaptation of the computer model for the specific product has been conducted by different expert teams within the LCA field in Finland, Norway and Sweden.
The data is aggregated with the LCAiT (LCA inventory tool) software developed by Chalmers Industriteknik, Sweden and the evaluation is performed with the Microsoft Excel programme.
The evaluation has been conducted with three different evaluation models; The effect-category method - CML (Leiden, Holland. Adapted to Swedish environmental goals), Environmental Priority Strategies in product design - EPS (Steen/Ryding, Sweden) and The Ecological Scarcity Method - BUWAL (Switzerland. Adapted to Norwegian and Swedish conditions).
In order to supply data and make a critical review of the work a reference group has been connected to each study. The reference group has consisted of representatives from the specific product group concerned. For example in the study of road surface materials the reference group have consisted by representatives from the asphalt and ready mixed concrete industries as well as contractors and road authorities.

4 Results

4.0 General

From the LCA a lot of different aspects can be quantified and presented according to the use in the particular case. In each study the functional unit is described and the inventory data reflecting its environmental characteristics is displayed, for example energy use and emissions to air. This information provide the base for environmental product information.

The evaluations conducted with the three evaluation models mentioned above, are presented graphically to visualise the significant environmental effects.

It should be nothed that the evaluation models sometimes give different environmental ranking when comparing alternative constructions.

4.1 Cement and concrete. Cradle to gate [1]

The first product study comprised the production of cement and concrete. The production processes for all seven cement plants of Finncement in Finland, Norcem in Norway and Cementa in Sweden where examined in detail from the limestone quarry to the transport to customer.

The database was integrated in a computer model which today is used operationally as a decision making instrument in the environmental improvement schemes for the cement production and also in all product developments.

To illustrate the operative use of the LCA-data model the effect of the improvement plans 1996 to 1999 for the Swedish plants is presented in diagram 1. The diagram also shows that emissions of C02, NOx and SO2 and the use of fossil fuel are the major contributors to the environmental impact of cement production.

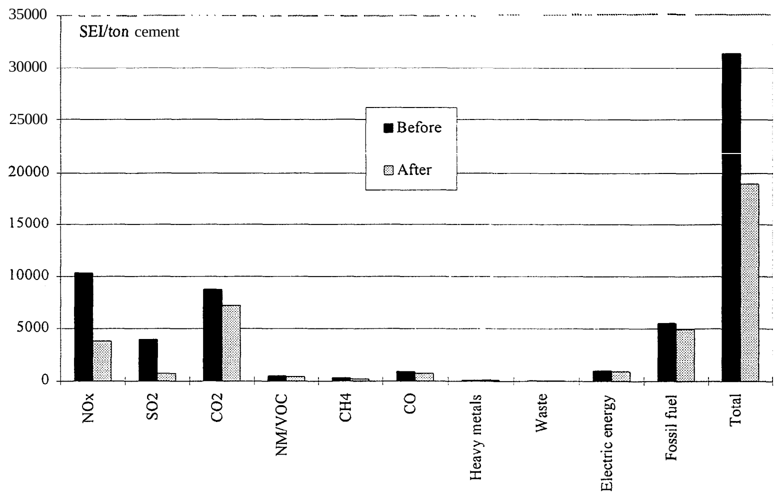

Diagram 1. Evaluated environmental effects of improvement scheme 1996 to 1999. Mean values for Swedish cement plants. Effect category method. Note that all the following presentations are based on cement data prior to the improvement scheme.

The cement content in concrete varies between 10 and 20 % by mass and the environmental characteristics of the production of concrete is closely related to the production of cement as can be seen in figure 5 below.

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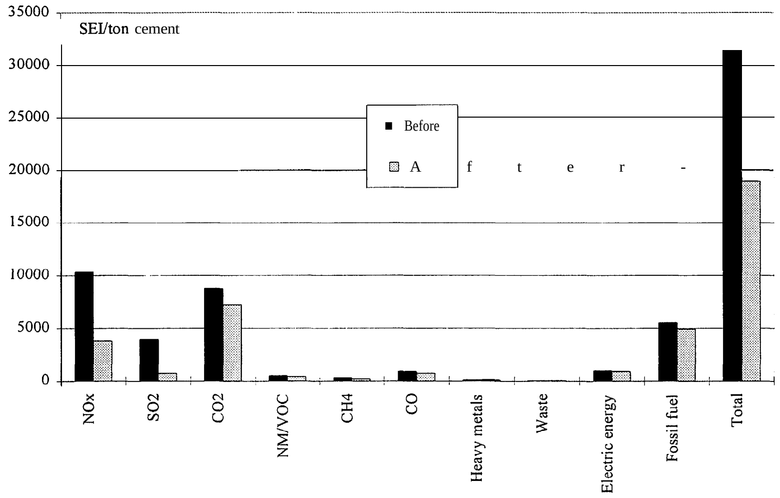

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4.2 Asphalt and concrete paving. Cradle to grave [2]

The object of the study was to assess the environmental impact of road pavements including maintenance. In order to establish relations to other user phase impacts the fuel consumption of vehicles and the energy use for lighting of the road was also quantified. The functional unit was defined as one km of a motorway close to Tampere in Finland with a traffic of 20.000 vehicles per day and a life span of 50 years.

Regarding the production of the pavement the inventory results for the most significant environmental aspects are presented in diagram 2. As can be seen the material characteristics differ significantly without giving any clear indication on which material is environmentally favourable. Applying the different evaluation models on this inventory data give no consistent answer. Using the Eco-Scarcity model asphalt is advantageous whereas using the EPS or the Effect Category methods concrete is preferred.

Regarding the entire life cycle including traffic and lighting the environmental effect of producing the pavement becomes negligible. See diagram 3

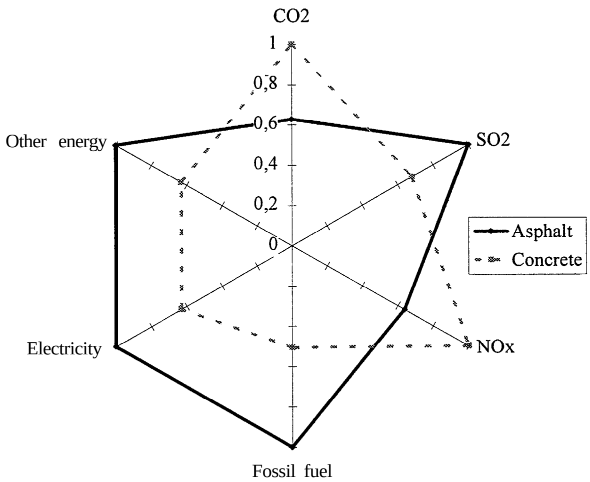

Diagram 2. Environmental characteristics of asphalt and concrete pavements.

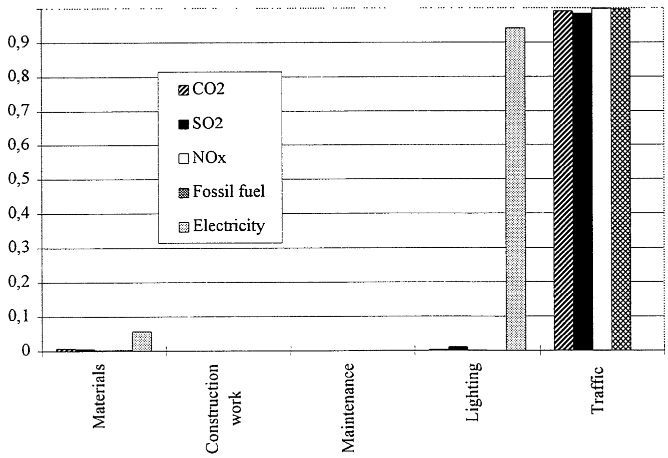

Diagram 3. Relative impact of the environmental burdens of paving and user phase of motorway during 50 years.

4.3 Concrete sewage water pipe. Cradle to grave [3]

In this study the total life cycle of a one km long concrete sewage water pipe line was inventoried and analysed. Data for unreinforced concrete pipes with a given diameter from three different concrete pipe producers in Sweden were gathered and specific data on excavation and other construction works were collected from the city of Gothenburg.

In diagram 4 below the distribution of environmental load according to the three chosen evaluation methods and also gross energy use is displayed.

As could be expected the cement production is a substantial contributor to the environmental load but the most interesting aspect is that the transfer of filling materials by far carries the environmental burden for the pipe line. Thus the environmental performance would benefit from techniques were the excavation is minimised.

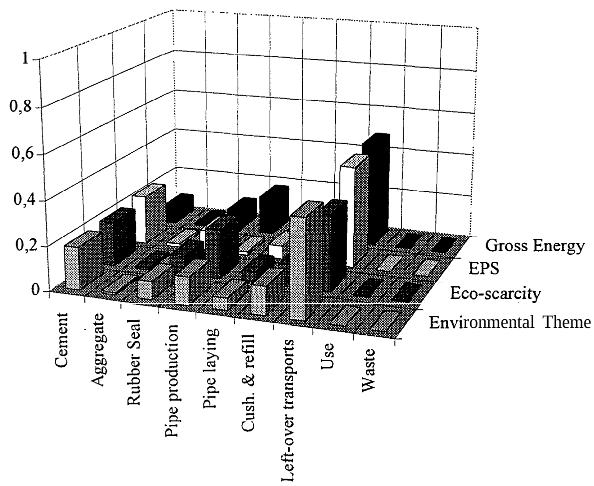

Diagram 4. Summary of the evaluation of the environmental impact of a concrete sewage water pipe line.

4.4 Building frames of concrete, steel and timber. Cradle to grave [4]

The scope of the frame study was to map the external environmental effects of building frames over the whole life-cycle. The following building frames for multi storey office or residential buildings in the Nordic countries were analysed;

In situ cast concrete, precast concrete, steel frame and hollow core slabs, in situ cast concrete with precast floor plates, steel frame with in situ cast concrete on precast floor plates, steel frame with ligth deck and timber frame.

In order to limit the amount of input data a segment of a frame was studied. See figure 1. The environmental load was related to 1 m2. of floor area during 50 years service life. The location of the building was defined to central Sweden in order to get comparative transport distances for components and materials.

Relevant portions of facades and interior walls areas were included.

Surface materials like paint, wall paper, carpets and installations were excluded.

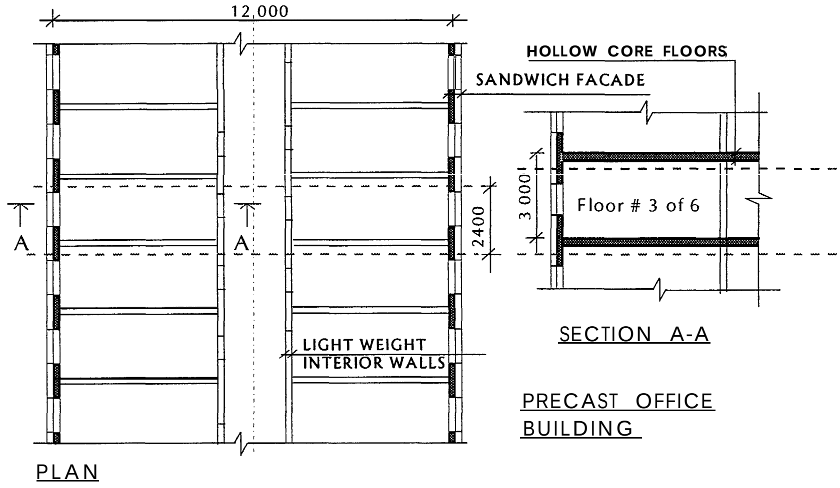

Figure 1. Definition of functional unit for building frame.

For the precast concrete as well as ready mix production specific plants was inventoried. For steel production general data for the Swedish steel industry with specific data for transportation distances have been used. For other materials like plasterboards and insulation general data from manufacturers have been collected.
General environmental databases are used for environmental data on transportation.
Environmental loads from the building site are related to the use of energy and generated waste.
For the service life general statistical data on the use of energy for heating and how this energy is supplied is used. A general overwiev of the positive effect of heat capacity in heavy buildings is presented but no evaluation of the behaviour of the different frame types in this study with respect to heat capacity was made.
The destruction phase adds to the environmental loads by the use of fossil fuel for demolition and transportation of waste material.
The LCA provides an effective tool for product improvement. In diagram 5 the distribution of one environmental parameter, - the energy use for a concrete floor, is displayed.

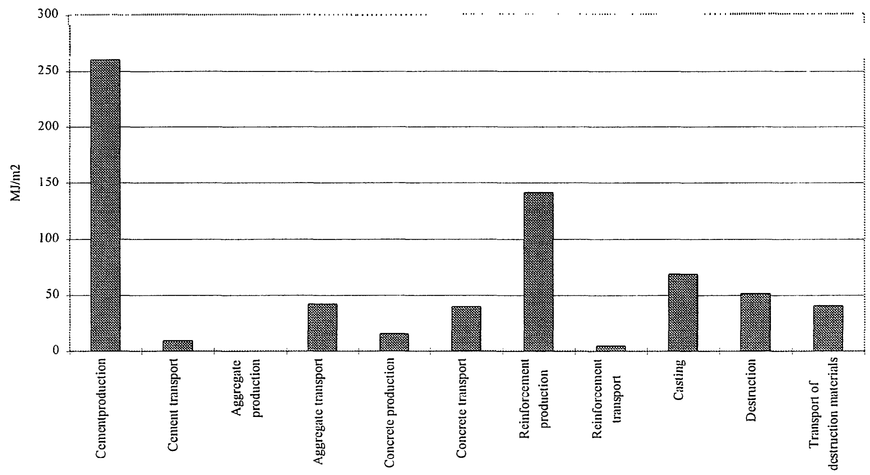

Diagram 5. Energy use for one m2. in situ cast concrete floor, H=200, over the whole life cycle. Energy for heating of the building during the user phase is not included.

The distribution of environmental loads evaluated with three different evaluation methods over the whole life cycle is presented in diagram 6

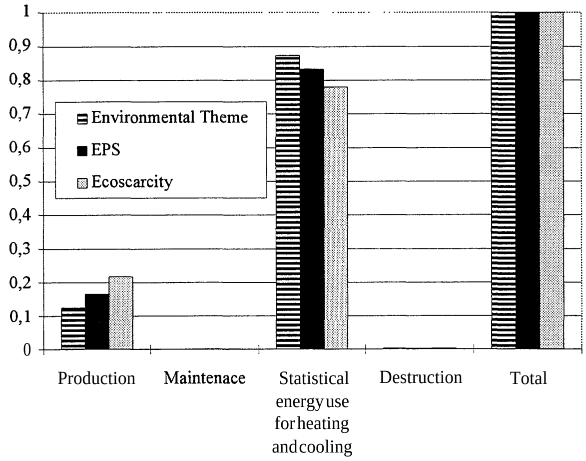

Diagram 6. Distribution of environmental loads of precast concrete frame over the life-cycle according to three different evaluation models.

A comparison between different frame types with four different frame types is presented in diagram 7.

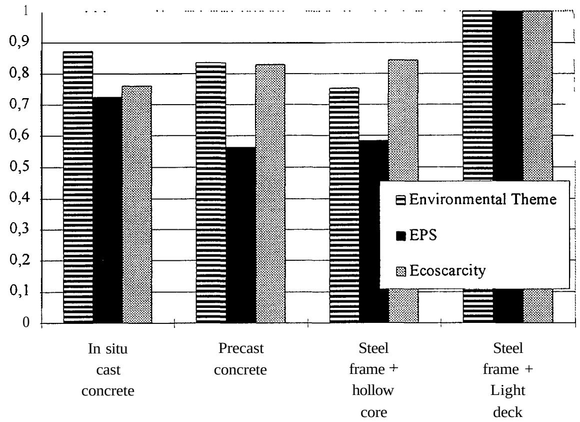

Diagram 7. Comparison of environmental load for the production of some of the frame types according to three different evaluation models.

The following conclusions can be drawn from the LCA-study on building frames;

- The difference in environmental impact from the production of the precast, in situ concrete and combined steel/concrete frames is small whereas the extreme light weight frames deviates more.
- Raw materials used are abundantly available with the exception of the fossil fuel.
- For the production phase the production of cement and steel are main contributors.
- The recycling possibilities of materials are important.
- Over the entire life cycle the user phase gives the highest environmental loads and the energy use for heating of the building is the dominating parameter.
- Because of the importance of the energy for heating (and cooling) during the user phase qualities like heat capacity are important.

- The environmental load from maintenance of a concrete or steel building frame is negligible.
- The impact of destruction is small and is related to the use of fossil fuels by transportation
- Some evaluation models give high response on waste which stresses the importance of minimising production waste and to recycle demolition waste e.g. as filling material.

5 Conclusions

LCA metodology is an adequate tool to map environmental effects of building materials and structures. The evaluation models should however be selected carefully and need some further elaboration to match the specific conditions applying to buildings regarding e.g. a long life cycle. Quite often applying different evaluation models will give disparate ranking between alternative constructions. Compare diagram 7, above.
High quality data on the environmental aspects of the production of cement and concrete have been generated.
The differences with regard to environmental characteristics between construction materials, when only production phase is considered, 'Cradle to gate', is small and in many cases insignificant as compared to the user-phase.
For products or materials with long expected lift-time the focus should be put on the user-phase performance. The user-phase usually accounts for over 80 % of the environmental loads. Careful urban development is a key factor for sustainability.
In the existing evaluation models little or no attention is given to the positive environmental value for the society, of building activities in the sense of providing buildings and infrastructure.
For the green procurement of buildings concrete is a good choice regarding components with long expected lifetime for example building frames, civil engineering works etc., were features like low need of maintenance or heat-capacity in houses are essential. Shorter life cycles of enhances production, destruction and recirceling aspects.

References

1. Vold, M., Rönning, A. *LCA of Cement and Concrete - Main report,* Stiftelsen Östfoldsforskning OR 32.95, Fredriksstad, Norway
2. Häkkinen, T., Mäkelä, K. *Environmental adaptation of concrete. Environmental impact of concrete and asphalt pavements.* VTT Research notes no. 1752, Espoo, Finland
3. Lundström, H., Öhlund, G., Rydberg, T. *Life cycle assessment of a concrete sewage pipe.* Chalmers Industriteknik, 1996, Gothenburg, Sweden
4. Bjorklund, T., Jönsson, A., Tillman, A-M. *LCA of Building Frame Structures.* Chalmers Techn. Univ. Technical Environmental Planning Rep. 1996:8 and 1997:2.

Presentation of Eco-Quantum, the LCA-based computer tool for the quantitative determination of the environmental impact of buildings

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Abstract
The Dutch government and building industry have agreed that life cycle assessment (LCA) should be the basis for the determination of environmental effects of (building) products. In order to provide architects and project developers with an instrument to measure the environmental performance of buildings, the Dutch government and other organisations financed the development of Eco-Quantum (EQ).

EQ is a computer tool on the basis of LCA which calculates the environmental effects during the entire life cycle of the building: from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse. This includes the impact of energy and water use, the maintenance during the use phase, the differences in the durability of parts or construction needs, like adhesives and nails. EQ also takes into account the possibility for selective demolition or renovation. The method can be used for both dwellings and non-domestic buildings.

Two types of computer tools are developed and will be presented at the conference: EQ-domestic and EQ-research. EQ-domestic is a tool for architects. With this instrument architects are able to quickly include environmental consequences of material, water and energy use in their designs of domestic buildings. So Eco-Quantum can be used to communicate on issues related to sustainable building between various partners, like project developers and designers. EQ-research is the tool for developing innovative designs for sustainable buildings and offices.

Keywords: Eco-Quantum, computer tool, building design, life cycle assessment, quantitative, environmental impact

1. Introduction

The life cycle of a building is responsible for a considerable part of the environmental effects caused by human activities. It is therefore important to dispose of instruments which show the environmental consequences of decisions of a building design. Two types of computer tools are developed in the Netherlands which enable architects and project developers to measure the environmental performance of complete buildings on the basis of LCA. They are named Eco-Quantum Domestic and Eco-Quantum Research. With Eco-Quantum Domestic architects are able to quickly identify environmental consequences of material choices and water and energy consumption in their designs of domestic buildings. Eco-Quantum-Research is the tool for in depth analysing of the environmental performance of buildings and developing innovative designs for sustainable houses and offices.

The Dutch government and building industry have agreed that life cycle assessment (LCA) should be the basis for the determination of environmental effects of buildings and building products. In order to provide architects and project developers with an instrument to measure the environmental performance of buildings, the Steering Committee for Experiments in Public Housing, the Dutch Building Research Foundation, the Association of Dutch Architects and the Dutch government financed the development of Eco-Quantum.

Until recently, only LCA's of building components and materials were carried out. But, a building is more than adding the various components, for example the life cycle of a building is important. Therefore IVAM Environmental Research and W/E consultants sustainable building developed Eco-Quantum, a computer tool on the basis of LCA which calculates the environmental effects during the entire life cycle of a complete building: from the moment the raw materials are extracted, via production, building and use, to the final demolition or reuse [1, 2, 3]. This includes the impact of energy and water use, the maintenance during the use phase, the differences in the durability of parts or construction needs, like adhesives and nails. EQ also takes into account the possibility for selective demolition or renovation.

2. General lay out of Eco-Quantum

Eco-Quantum consists of 3 related programmes, Eco-Quantum Research, Eco-Quantum Domestic and SimaPro. Databases are another part of Eco-Quantum. The two most important databases are: the database Components and the database Environmental Profiles.

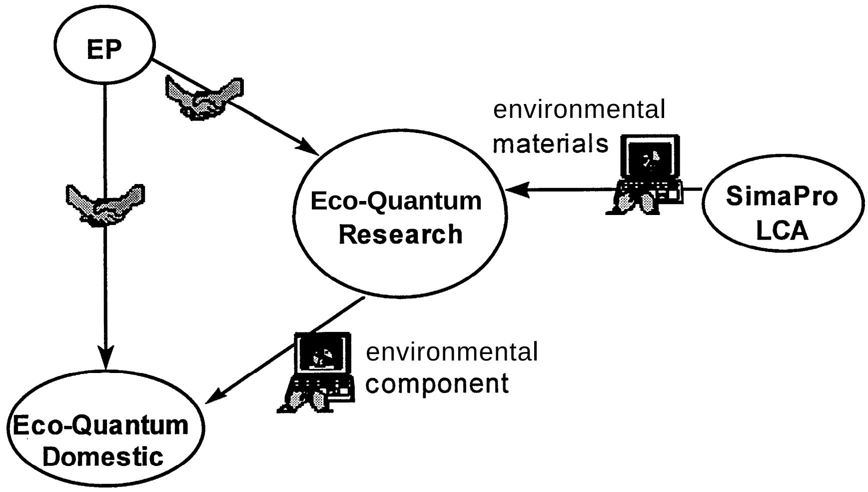
In figure 1 the general lay out of Eco-Quantum is presented. Eco-Quantum Domestic and Eco-Quantum Research are provided with information from a stand-alone version of the Dutch LCA programme SimaPro 4 [4] and the Dutch Environmental Performance Standard (EP). SimaPro calculates split environmental profiles per kilogram building materials and for processes related to the production of energy and water, transportation and waste processing. These environmental profiles are the input to the database Environmental profiles in Eco-Quantum Research. The Dutch Energy Performance standard is applied to determine the energy consumption during the use of the building.

Architects provide the input of the design: materials and quantities of the building components of the design, together with figures about energy and water consumption. Eco-Quantum translates this in kilogram materials and water flows and MJ energy. For this Eco-Quantum comprises of an extensive database components which consists of materialised components of the building, with information about life span, materials needs, maintenance and waste scenarios.

In order to calculate the environmental performance of a building the environmental information from the database Environmental profiles is connected to the material, water and energy flows of the building. By doing this the environmental interventions related to the total life cycle of the building are accumulated. Furthermore the environmental interventions are converted on the basis of characterisation factors of the LCA methodology of Heijungs et ***al.*** [5] into 11 environmental effectscores such as raw material depletion, ecotoxicity and greenhouse effect. In a following step these 11 effectscores are converted into four environmental indicators: raw material depletion, emissions, energy consumption and waste according to the Dutch project “Environmental Ratings in the construction industry set up by the Council for the Construction Industry (see figure 3).

Various outputs can be presented in de from of environmental indicators, environmental profiles and material flows.

Figure 1 Subsystems Eco-Quantum



Eco-Quantum

3. EQ domestic

Performing LCA of complete buildings is normally a complex and time consuming task. Environmental requirements are added to an enormous amount of design requirements which architects have to consider for designing a building. If an instrument does not consider this complex task and the time constraints of architects, it won't be used in a design process.

Against this background EQ domestic is developed as a practical computer programme which enables architects to quickly reveal the environmental performance of a housing project. In order to do so environmental information about standardised building components is prepared in Eco-Quantum Research for Eco-Quantum Domestic in the form of environmental profiles of components (see figure 1).

If the specifications of a building design are available it is possible to determine the environmental impacts in about a half an hour. The environmental profiles of standardised components in Eco-Quantum Domestic serve as an aid to the architect. The user can indentify the most important causes of the environmental impacts, make changes in the design of the building and evaluate the alternative solutions.

The user performs the following steps in EQ domestic:

- **enter information about the building project**

In order to calculate the environmental performance of a housing project the user opens a new project en describes it by filling in the name and other general information. It is expected that various design variants will be developed. Therefore the user also gives each variant of the project a unique name. Eco-Quantum connects to each variant a tree structure which consists of 4 levels: the complete building, 8 building parts, 24 building elements and about 60 building components. The structure of the tree follows the structure of the Dutch NL/SfB Building element method.

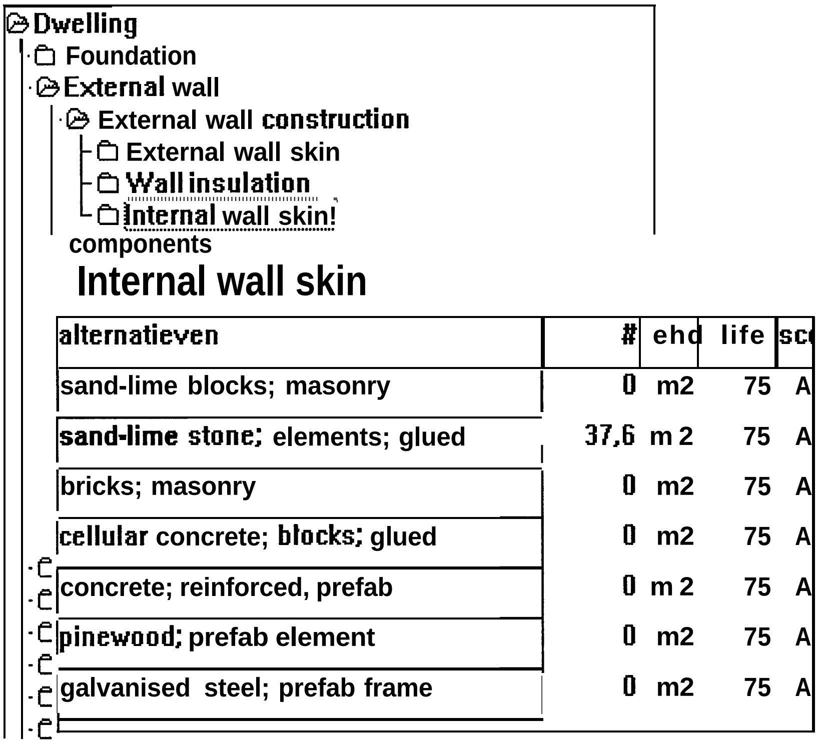
- **enter the design data of the project**

In Eco-Quantum Domestic the input of a design is as limited as possible. In figure 2 an input screen is presented. In the upper part of the figure a small part of the tree is shown following the four levels:

- building
- 8 building parts, e.g. external wall
- buildings elements: only one building element is folded out: e.g. external wall construction
- buildings components: only one component is folded out: e.g. internal wall skin

The architect folds out one element (in this case external wall construction) and selects one component (in this case the inner side of the cavity wall, the internal wall skin). In the lower part of the screen the architects enters the necessary design information in the form of the amount of walls (37,7 m2). Furthermore the architect can change the life span (here 75 years) and choose between demolition scenario A (current situation) and B (optimised situation). After finishing the input for this component Eco-Quantum Domestic automatically goes to the following component. Besides this information both the information about energy consumption and water consumption of the specific design is entered in the programme.

Figure 2. Input screen and part of the tree



- **calculate the environmental profile of the building**

On the basis of these inputs the programme calculates the environmental performance of the building. First, Eco-Quantum relates the environmental profiles to the corresponding material, energy and water flows. By doing so the environmental interventions related to the total life cycle of the building are accumulated in the form of raw materials, energy input, waste and emissions. Second, the environmental interventions are converted on the basis of characterisation factors of the LCA methodology [5] into 11 environmental effect scores such as raw material depletion, ecotoxicity and greenhouse effect. In the following step these 11 effect scores are automatically converted into four environmental indicators: raw material depletion (exhaustions of resources), emissions, energy consumption and waste according to the Dutch Environmental Rating methodology (see figure 3).

- **presentation of results**

The user can choose between various kinds of output depending on the question to answer. The three possibilities are:

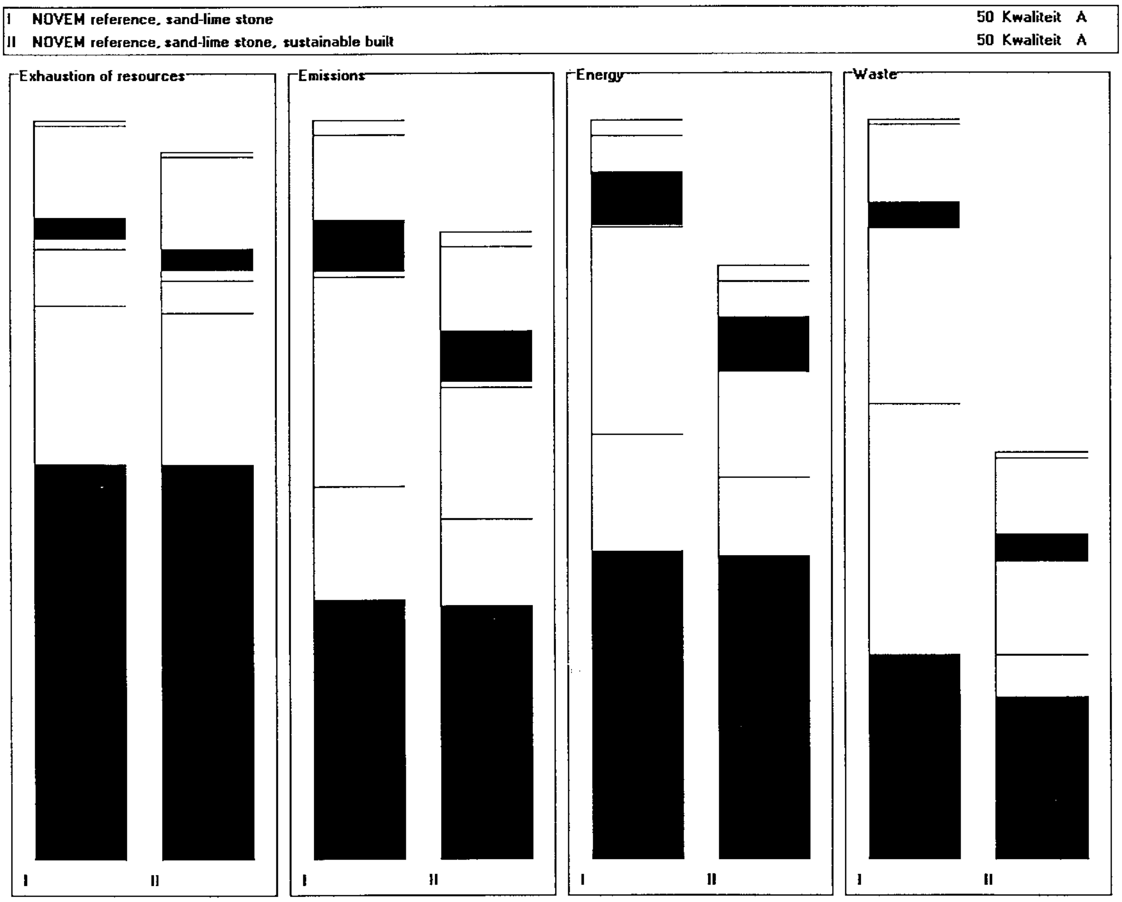
1. an overview of materials streams
2. 11 effect scores, according to the life cycle analysis of Heijungs.
3. 4 environmental indicators, according to the “Environmental ratings in the constructions industry” (exhaustion of resources, emissions, energy and waste)

If an architect wants to detect the causes of the environmental burden of the design it is possible to give a division of the environmental impacts over the stages of the life cycle of the parts, elements and components of the building.

- **optimise the environmental profile of a design**

The user can environmentally optimise the design in various ways. The components and constuctions at which the largest environmental benefit can be obtained are indicated. So the user can optimise these with the material alternatives offered. So the environmental burden can be reduced mostly. The user can also select alternative building components and constructions and see what the impact is on the environment. Of course, installation concepts for reducing energy and water consumption can also be changed, just like the life span, and the use of secondary materials and recyclable products.
Eco-Quantum Domestic enables the architect to easily change the input and quickly calculate the new environmental profile and compare the original design with the optimised one (see figure 3).

Figure 3 Output: comparing the original and the optimised design



- **compare the environmental performance of various designs**

In figure 3 the environmental profile of a standard sand lime brick house is compared to an optimised sand lime brick house. In the latter the improvement options from the Dutch manual for sustainable building: Nationaal pakket Woningbouw (National Package Sustainable Housing) [6] are implemented. Examples are energy saving installations, better insulation, less use of scare materials and wood from not-sustainable managed woods.

4. EQ research

Eco-Quantum Research is the instrument for in depth research of the environmental impacts for all types of buildings by researchers, consultants and large design offices. An important difference is that in Eco-Quantum Research users can enter new building components whereas Eco-Quantum Domestic works with fixed standardised building components. This makes Eco-Quantum Research a tool which is suited for all building types. The environmental impact of any building type can be calculated with it, like schools, hospitals and other health buildings, offices and other industry buildings. This can on the other hand make EQ Research a more time consuming instrument. A user can, but is not obliged to, add self made building components. If the user wants add components, he of she has to enter the design data himself, for example material consumption per square meter, building waste, time span and waste scenario.

5. Concluding remarks

Both the prototypes of Eco-Quantum Domestic and Eco-Quantum Research will be presented by W/E consultants sustainable building and IVAM Environmental Research at the conference in order to enable participants to see the details of the programme.

Eco-Quantum makes it possible to communicate on the environmental impact of buildings during the design of a building. By presenting quantitative results in a relatively simple way, architects can improve the environmental quality of a building themselves. Other qualities of a building are of course at the same time considered. And Eco-Quantum enables them to communicate with their initiators and future owners.

References

[1] Mak, J.P., Anink, D.A.F., Kortman, J.G.M., Lindeijer, E., van Ewijk, H. *(1996) Eco-Quantum, final report: design of a calculation method to determine the environmental load of a building in a quantitative way* (in Dutch), Gouda, The Netherlands.

[2] Mak, J.P., Anink, D.A.F., Kortman, J.G.M, van Ewijk, H. (1996) *Eco-Quantum 2, final report: sensitivity analysis* (in Dutch), Gouda, The Netherlands.

[3] Mak, J., Anink, D., Knapen M. (1997) *Eco-Quantum, development of LCA based tools for buildings,* in Proceedings of CIB Conference Task Group 8, Buildings and the Environment, June 9-12 Paris, France

[4] Pré Consultants B.V. (1997) *The new SimaPro 4 for windows,* Amersfoort, The Netherlands.

[5] Heijungs, *R. et al.* (1992) *Environmental life cycle assessment method of products,* Centre of Environmental Science Leiden, The Netherlands.

[6] Dutch Building Research Foundation (1996) *National Package Sustainable Housing,* Rotterdam, The Netherlands

Studies of hydrophobed plastered autoclaved aerated concrete

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Abstract
The service life of external building materials largely depends on the severity of the micro climate and the properties of the material itself. The rainwater is the most effective environmental agent, particularly on porous building materials, either as a harmful agent itself or as a means of several degradation mechanisms resulting from the combined attack with other weathering agents. Thus the moisture characteristics of the material play an important role in determining its durability.

As most of the damages are related to water, measures must be taken against the ingress of water into the structure. The use of surface treatments for the protection of porous building materials against rainwater extends the service life of the component. The silicon-based water repellants are increasingly used due to their hydrophobic properties.

In order to evaluate the performance of the hydrophobed porous building materials, some laboratory tests have been carried out on autoclaved aerated concrete (AAC) specimens, rendered with different combinations of plasters and hydrophobed with silicon compounds. Common properties, such as capillary water absorption and vapour permeability were tested. This paper reviews degradation mechanisms related to rainwater and the general properties of surface treatments. Brief results on moisture characteristics of plastered AAC with and without water repellants are presented.
Keywords: Autoclaved aerated concrete, surface treatments, water repellants, degradation, moisture properties

1 Introduction

A large number of buildings have various problems due to exposure to wind-driven rain and water vapour from the inside. Failures of facades can be seen both on existing old and new buildings. Agents originating from the atmosphere are most relevant for the ageing process of the materials used in the exterior envelope of the buildings. External walls are deteriorated by the atmospheric agents in scale of components and materials, especially on facades exposed to wind-driven rain. The severity of damage is increased by the combined attack of the weathering elements like solar radiation, rain, air constituents and contaminants and freeze-thaw cycles.

When porous building materials are subjected to rain, an inward transport of water occurs. Water penetrates through the capillaries, cracks and joints by wind and capillary suction forces directed into the building enclosure. The absorption rate depends on the pore structure of the substrate and the hydraulic properties of the surface. The rate of drying after wetting is also dependent on the porosity of the material and the ambient temperature, relative humidity and wind velocity.

In fact, the wetting of the walls is due not only to rain but also to condensation phenomena. Vapour permeable waterproofs should be applied to vapour permeable substrates in order to allow vapour to pass through the coating to the outside of the building. Otherwise, vapour condenses at the interface of the nonpermeable layer, causing deterioration. Therefore, the continuity of the moisture transport through the different layers of the wall, that is, the vapour permeability of the whole wall system, plays an important role in proper material selection.

The use of surface treatments for the protection of porous building materials against water ingress is expected to extend the service life of the walls by raising their performance. However, surface treatments should not affect the vapour transmission as not to cause condensation in the wall structure.

2 Degradation mechanisms related to rainwater

Rainwater is the major destructive atmospheric agent for most external building materials. The amount of water hitting a wall depends on the intensity of driving rain, which in turn is directly proportional to the amount of rainfall and the wind velocity during rain.

Volume changes, as expansion on exposure to moisture and contraction during drying out, result in cracking or surface crazing of porous building materials. The flow of water over surfaces or splashing back of water against surfaces from rainfall causes change in appearance of facades, such as staining.

Water transports salts within the wall structure and deposits them on the surface of the porous material by evaporation. This phenomenon is known as efflorescence. The crystallisation of soluble salts within the pores beneath the exposed surface within the structure is referred to as ‘cryptoflorescence’. The white deposits of soluble salts on surfaces can lead to change of appearance as well as give rise to deleterious effects by the reversible uptake of water. Cryptoflorescence may cause loss of adhesion of external wall finishings such as renderings and surface coatings and leads to embrittlement and crumbling of the surface material as a result of crystallisation pressure [1]. Formation of these crystals can trap moisture in masonry pores, which cause spalling during freeze-thaw cycles. Additionally, if cryptoflorescence is severe enough, it prevents the natural moisture transport properties of the masonry wall.

When porous building materials are exposed to low temperatures, the water in the capillary pores freezes and stresses produced lead to deterioration. The frost resistance of the material is mainly influenced by the water content and the pore structure of the material. For the deterioration mechanism the influence of water content is related to a value known as 'critical water content', below which materials are resistant to frost action. Therefore the permeability of a material plays an important role in frost action. The most common frost damage, such as cracking and spalling, is caused by progressive expansion from repeated freeze-thaw cycles. By preventing water penetration, substrates will also be protected from the damaging effects of freeze-thaw cycles.

Ultraviolet radiation received on the surfaces of buildings causes degradation particularly when it acts in conjunction with oxygen, water, heat or a combination of these agents. Loss of appearance, fading, yellowing, and erosion are common UV failure modes. UV also contributes to the loss of protection properties such as water repellency.

Sulphates and nitrates in the air form sulphuric and nitric acids by reacting with rainwater (acid rain), which acids are transported deep into the porous material via wet deposition and capillary suction. They attack the calcium compounds of the substrate, causing deterioration.

Fine particles of atmospheric dirt settle at building surfaces and the contaminated rain falls at and runs off the same surfaces. The flow of water may wash the particles out but usually redeposit them, the outcome depending on direction and rate of the flow. Porous materials trap the particles in their pores [2].

In addition to the deterioration effects of water, the high moisture content declines the thermal performance of the wall, bringing significant energy losses.

3 Surface Treatments

Surface treatments are used as a preventive measure for improving the performance of porous building materials against external degradation agents. As most of the damages are related to water, the protection is usually intended to reduce the absorption of water in the material.

Surface treatments can be classified in four main groups according to their protective action [3] :

- penetrant / pore liners
- penetrant / pore blockers
- sealers and coatings
- cementitious coatings

3.1 Pore-liners

These treatments line the pore surfaces of the substrate by a chemically bonded water-repellent hydrocarbon molecule [4]. As they do not block the pores, the effect on the vapour permeability of the wall is negligible. As the surface treatment is colourless, it makes very little change on the appearance of the facade.

By penetrating the substrate, the material itself is shaded and thus highly protected from the UV radiation. Accordingly, a long term durability is achieved. The performance of the pore-liners largely depends on properties of the substrate, such as porosity and moisture content and on the amount of material applied.

Silanes, siloxanes and silicon compounds are examples of this type.

3.2 Pore-blockers

These treatments penetrate into the substrate and clog the pores. In this way water is repelled along with any dissolved salts, acids and other aggressive agents. This treatment is also known as the crystal growth method. The crystalline reaction products bind to the water molecules and increase in volume.

The vapour transmission is greatly restricted by the blockage of the pores. Improper application can cause water uptake by capillary action. Pore-blockers have no effect on the appearance of the surface. They are usually used for hardening of the surface and as a primer before the main coating.

The most common examples are silicates, silicofluorids and some kinds of epoxy and acrylic resins.

3.3 Sealers and coatings

By forming a pinhole-free, continuous film layer on the surface, sealers and coatings prevent the water ingress but obstruct also the vapour diffusion. Owing to their penetration into the substrate to some degree, sealers have a good adhesion to the substrate and are often used as primers. Film forming surface coatings can be pigmented when colour is desired.

Epoxy resins, polyurethanes, acrylics, linseed oil, alkyds, vinyls, chlorinated rubber, styrene-butadiene, cement based stone paints and bitumens are the typical examples of sealers and coatings.

3.4 Cementitious coatings

These are cement-based products containing finely graded siliceous aggregates. Chemical additives impart integral water repellency and improve the adhesion of the coatings to the substrate. Since cementitious coatings are water-repellent, they are highly resistant to freeze-thaw cycles. The performance against weathering is excellent, while the resistance to acid rain and other contaminants is poor.

These products are also vapour permeable, allowing transmission of vapour. Cementitious coatings adhere well to the substrate and are considered as an integral part of the substrate. But they do not function if cracking or substrate movement occurs.

The coatings completely change the original appearance of the facade. Pigments are added to colour and various textures are available, either by coarseness of aggregate or by application methods [5].

4 Silicon-based water repellants

Silicon-based water repellants are considered as the best protective agents against aforementioned facade failures. They are colourless, low viscous, capillary active liquids which act by forming a hydrophobic zone against water. The effect of water repellants is based on their low surface tension. They are claimed to satisfy requirements as [6]:

- excellent water repellency
- high vapour permeability
- good adhesion
- excellent durability (resistance to weathering, e.g. UV)
- solvent-free (environmentally friendly)
- no change in appearance.

Silanes and siloxanes have the best performance characteristics and long-term durability among the silicon compounds. They have t-structured molecules containing three silicon functional groups and one organofunctional group. While siliconates also belong to this group, they are no longer used for protecting facades. The reason is that a white layer is formed on oversaturated areas, which is hard to remove [7].

The hydrophobicity is provided by the organofunctional (alkyl) groups of the compound. The penetration depth into the substrate is determined by silicon functional (alkoxy) groups and affects the long-term durability of the repellant. By penetrating the substrate, the alkyl group is protected against UV radiation. Factors influencing depth of penetration include the porosity (particularly on the surface), moisture content of the substrate, molecular size and amount of water repellant agent applied [4]. The molecular size of silanes (10-15 A) and siloxanes (25-75 A) is small enough to permit the compounds to enter the pore structure of concrete (20-200 A).

The water-repellent hydrocarbon molecule (alkyl group) chemically bonded to the substrate, reduces the surface tension of the substrate. Different alkyl groups reduce the water absorption to various levels. The water absorption rate is represented by the water absorption coefficient of the surface coating, A [$kg/m^2h^{0,5}$]. This coefficient describes the water absorption of a wall when a film of water occurs at the surface. The behaviour of water when in contact with the surface of the material is governed by its surface tension which is measured by the contact angle.

5 Experiments

In order to study the performance of porous building materials against weathering, the moisture characteristics of hydrophobed plastered autoclaved aerated concrete (AAC) were tested. The hydrophobic properties of the sample components, i.e. capillary water absorption and vapour permeability were taken as performance parameters.

5.1 Materials

Tests were carried out on ten AAC specimens, rendered with five different plaster systems with and without silicon. Two different water-repellent products were used; as an additive in the plaster and as a treatment at the surface of the AAC. The water repellant used as an additive is a powder consisting of a silicon resin on a carrier matrix and forms pores in the plaster. The plaster gets flexible and thus has a low tendency to crack. The water repellant used as surface treatment is an aqueous silane/siloxane emulsion. It is solvent-free and water thinnable.

The plaster systems used are (in general) as following:

A1: Two layered thin plaster, (4 mm); primer and a sprayed topcoat
A2: Two layered thin plaster, (4 mm); primer with silicon additive and a sprayed topcoat with silicon additive
B1: Three layered plaster (17 mm); primer, lime-cement undercoat and a sprayed topcoat
B2: Three layered plaster (17 mm); primer with silicon additive, lime-cement undercoat with silicon additive and a sprayed topcoat with silicon additive
C1: Four layered coating (17 mm); primer, lime-cement undercoat, acrylic primer and a acrylic plaster as topcoat
C2: Four layered coating (17 mm); primer with silicon additive, lime-cement undercoat with silicon additive, acrylic primer and a acrylic plaster as topcoat
D1: Monosystem plaster (18 mm)
D2: Monosystem plaster (18 mm); (AAC surface treated with silicon)
E1: Three layered coating (15 mm); hydraulic lime primer, hydraulic undercoat and a cement-dolomite paint
E2: Three layered coating (15 mm); (AAC surface treated with silicon), hydraulic lime primer, hydraulic undercoat and a cement-dolomite paint.

5.2 Tests

Specimens in dimensions of 150*150*70 mm^3 were used in the capillary absorption test. The faces of the samples, except the surface to be immersed, were sealed water and vapour-tight. The samples were immersed in 1-3 mm of water (Figure 1). The samples were weighed at the start of the test before immersion and at various time intervals. The water level was kept constant during the experiment.

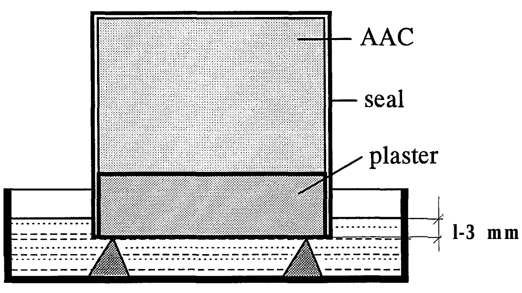

Figure 1 Capillarity test set-up

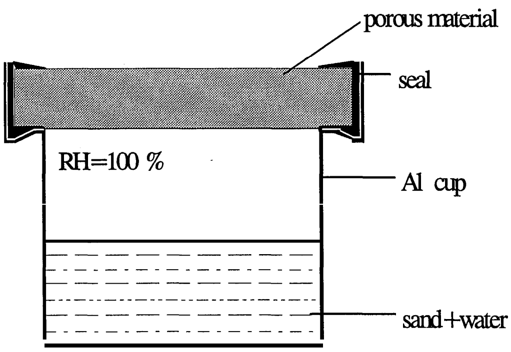

Figure 2 Wet cup method

The vapour permeability tests were carried out in accordance with the wet cup method. Cylindrical specimens with a diameter of 90 mm were placed in aluminium cups containing sand and water (Figure 2). The edges were then sealed so that only the upper and the lower surfaces were exposed. The cups were stored in the climate chamber at 20^0C and 65 % relative humidity. Changes in the mass of water in the cups were determined by weighing at certain time intervals.

5.3 Results

In Table 1, the samples are identified according to the existence and type of the water-repellent material. The water absorption rates at 24 hours and the reduction gained by water repellants are given in Table 2.

Table 1 Summary of specimens

	samples without repellant	samples with repellant
repellant as additive	Al	A2
	B1	B2
	Cl	c2
repellant as surface treatment	D1	D2
	El	E2

Table 2 Summary of best performance

samples	Water Absorption Rate [kg/m²$h^{0,5}$] without repellant	with repellant	Reduction %
A	2,12	1,18	44
B	1,67	0,25	85
C	0,99	0,22	78
D	1,90	0,67	65
E	2,15	0,55	74

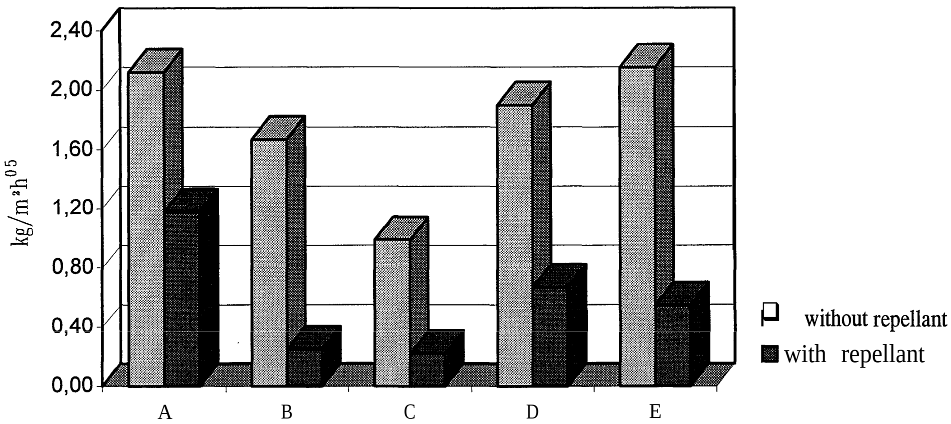

Figure 3 The water absorption rates for 24 hours

Samples B2 and C2 have the best performance among the plaster systems as can be seen from the diagram in Figure 3. The capillary water absorption curves are given in Figure 4 for both short and long periods. Unlike. the hydrophobed plaster systems B2 and C2 (though, the same water-repellent additive was used), the water absorption of the specimen A2 is significantly higher in the long period. The most likely explanation to this is the specific pore structure of the plaster and also its thickness.

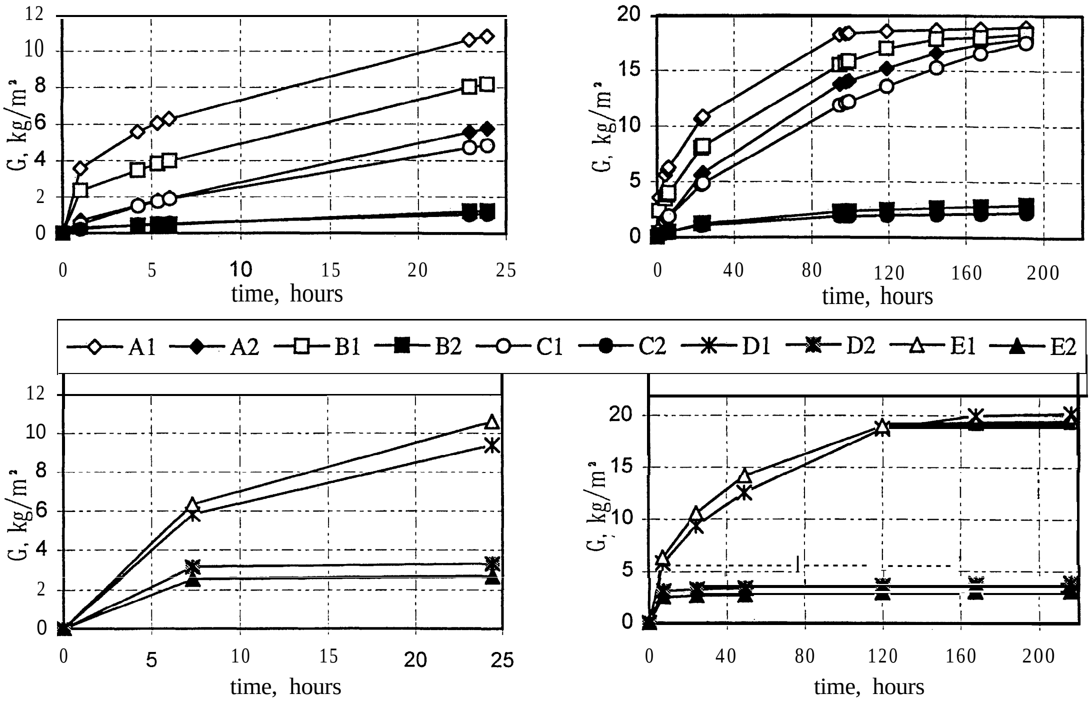

Figure 4 The capillary water absorption of the specimens

Diffusion resistances (the vapour diffusion resistance-equivalent air layer thickness, s_d), of the sample coatings are summarised in Table 3 and given as a diagram in Figure **6.** The results indicate that the water-repellent products used do not have a considerable effect on the vapour permeability of the sample components.

Table 3 The water vapour diffusion resistance-equivalent air layer thickness, s_d [m] values of the specimens

samples	without repellant	with repellant
A	0,141	0,122
B	0,307	0,334
C	0,439	0,357
D	0,151	0,215
E	0,175	0,198

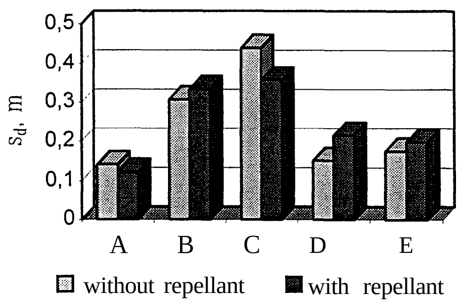

Figure 6 The s_d values of the specimens

6 Concluding Remarks

The test results indicate that the application of a water repellant on the surface of AAC, under the plaster, is not as effective as the water repellant applied as additive in the plaster. Hence, repellant as a surface treatment between the layers, may act as a barrier and cause accumulation of water at the interface, leading to deterioration. The application of repellant at the top surface of the plaster would perform better only if the surface remains free of later cracks or spallings. This is even verified by the outcomes of the experiments which are still going on to investigate the performance of water repellants as surface treatment on the plaster.

According to Künzel [8]; an exterior rendering can be termed 'water-repellent' (managing heavy driving rain conditions) only if it meets the requirements:

$A < 0{,}5\ kg/m^2h^{0,5}$ and $s_d < 2$ m;

and 'water-retarding'(managing medium driving rain conditions) if:

$A < 2\ kg/m^2h^{0,5}$ and $s_d < 2$ m.

The comparison of the test results indicate that:

- Only hydrophobed plaster systems B and C meet above requirements to be termed water-repellent
- All the plaster systems, hydrophobed or not, meet the requirements to be termed water-retarding
- All the plaster systems, hydrophobed or not, fulfil the above requirements for water vapour transmission.

The results obtained from the tests confirm the hydrophobic effect of water repellants on porous building materials. However, (in this case) the performance of repellants depends on the properties of the plaster system, its layers and its thickness. They also perform different depending on their application as additive or surface treatment. In order to make broader assessments, tests are continued with the samples treated with silicons on the top surface. Moreover, additional tests are planned to investigate the long-term performance of the water repellants on porous materials.

7 References

1. Addleson L., Rice C. (1991) *Performance **of Materials** in Buildings,* Butterworth Heinemann, Oxford.
2. Mays G. (1992) *Durability of Concrete Structures,* E & FN Spon, London.
3. CIRIA TN 130 (1987) *Protection of Reinforced Concrete by Surface Treatments,* CIRIA, London.
4. McGettigan E. (June 1992) Silicon-based Weatherproofing Materials. AC.'. *Concrete Int.*, USA.
5. Kubal M. T. (1993) *Waterproofing the Building Envelope,* McGraw-Hill Inc., USA.
6. Sandin K. (1995) Surface Treatment With Water Repellent Agents. *Proceedings **of** the First Int. Symposium on Surface Treatment **of** Building Materials with Water Repellant Agents,* Delft, Netherlands.
7. Mayer H., Roth M. (January 1995) *Silicon Microemulsion Concentrates, Wacker SMK 'A New Way **of** Obtaining Aqueous Masonry Water Repellants Based on Organo-silicon Compounds,* Munich.
8. Kunzel H. (1977) Evaluation of Renderings and Paintings with Respect to the Rain Protection. *RILEM/ASTM/CIB Symposium on Evaluation **of** the External Vertical Surfaces **of** Buildings,* Espoo, Finland.

Durability evaluation of newly developed fluoropolymer emulsion paints

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Abstract

A new type of water-based emulsion paints by using fluoropolymer have been on the market recently in Japan. These water-based paints are expected to decrease air pollution and also to keep such high durability as organic solvent type of paints.

This paper outlines the results of a series of performance evaluation tests for the new paints and other standardized paints such as solvent type of fluoropolymer paints, solvent type of polyurethane paints, and acrylic emulsion paints for comparison. A sunshine carbon arc type of irradiation test, outdoor exposure tests and corrosion tests for steel protective coating systems were carried out in the study. Moreover, repainting works with the new water-based paints and with other paints for exterior finishing systems were performed.

Through the sunshine carbon irradiation test and the corrosion tests, it was confirmed that the water-based fluoropolymer paints possessed competitive durability with solvent type of fluoropolymer paints which are more durable than solvent type of polyurethane paints. The outdoor exposure tests and periodical inspection for repainted exterior finishing have been continued for a few years. The fluoropolymer emulsion paints have shown good durability in the both tests. Finally, the draft of standard specifications of coating work with the fluoropolymer emulsion paints was obtained for both new painting works and repair painting works through this study.

Keywords: Air pollution, durability, fluoropolymer, paint, repaint, standard specification, water-based emulsion.

1 Introduction

According to the report [1] of Environment Protection Agency in Japan, about 30% of the total amount of organic carbons which were emitted into the air due to human activities has been considered to come from painting works. Different from coating in controlled manufacturing factories, it is difficult to collect organic solvents evaporated in the air, because painting works in construction are usually carried out in outdoor conditions.

For this reason, use of water-based paints has been recommended from the viewpoint of environment protection. This demand is becoming very strong recently. Paint manufacturers are intensively developing safer and more durable paints. Figure 1 shows fundamental methodologies for developing safer paints.

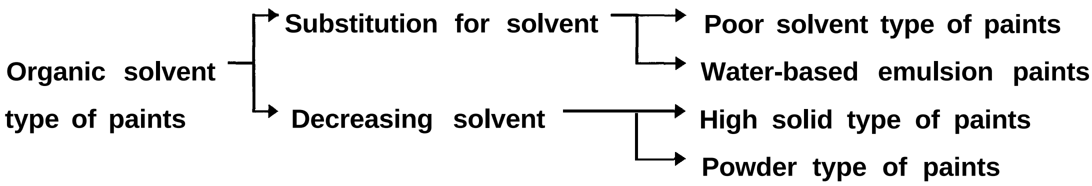

Figure 1 Basic methodology for developing environmentally safer paints.

Among the paints shown in Figure 1, poor solvent (mineral sprits, solvent with higher boiling point) type of paints, water-based paints and high solid type of paints have been on the market aiming at substituting for existing solvent type of paints used in construction works. Especially, water-based paints are considered to be suitable from the viewpoint of environment protection. However, water-based paints are generally less durable than organic solvent type of paints. Therefore, it is not so easy to replace water-based emulsion paints for existing solvent type of paints especially where high durability is required.

In this background, new type of emulsion paints by using fluoropolymer have been recently developed in Japan. As reported before[2][3], solvent type of fluoropolymer paints were already developed and have been prevailing in Japan. The durability level of these paints has been classified at the one of the highest ranks among the all types of paints on the market. The solvent type of fluoropolymer paints were already standardized in JIS K 5658[4] and JIS K 5659[5] for their materials qualities and the painting work specifications were also standardized in JASS18[6].

The newly developed emulsions consist of polymers whose molecular structures are similar with solvent type of fluoropolymer. One of the key points for imparting high durability to fluoropolymer emulsions is not to use usual emulsifiers. It is reported by the manufacturer that the durable fluoropolymer emulsion paints can be obtained by using macro-monomers compatible with both fluoropolymer and water as emulsifiers.

In this study, a series of tests including sunshine carbon arc irradiation test, outdoor exposure tests and corrosion tests have been conducted for the newly developed emulsion paints in order to evaluate their durability and applicability to construction work.

2 Experiment

2.1 Tested materials

The coating specifications listed in Table 1 and Table 2 were applied for cementitious substrate specimens and steel sheet specimens, respectively.

Table 1 Coating specification for cementitious substrates.

Coating system	Under coat	Top coat (dry film 40 μ m in thick)
System A	acrylic emulsion	water-based fluoropolymer emulsion
System B	epoxy primer	solvent type of fluoropolymer paint
System C	acrylic emulsion	water-based acrylic emulsion
System D	epoxy primer	solvent type of polyurethane paint

Substrate : fiber reinforced cement sheet (70mmx150mmx4mm).

Table 2 Coating specification for steel sheets.

Coating system	Under coat	Middle coat	Top coat (dry film 40 μ m in thick)
System E	anti-corrosive emulsion	none	water-based fluoropolymer emulsion
System F	anti-corrosive emulsion	acrylic emulsion	water-based fluoropolymer emulsion
System G	solvent type of anti-corrosive paint	none	water-based fluoropolymer emulsion
System H	solvent type of anti-corrosive paint	none	solvent type of polyurethane paint
System I	solvent type of anti-corrosive paint	none	solvent type of fluoropolymer paint

Substrate : cold rolled carbon steel sheet, ss400 (70mmx150mmx0.8mm)

2.2 Sunshine carbon arc irradiation

Sunshine carbon arc irradiation was performed according to IS0 4892-4[7]. The water spray cycle used was 18 min spraying with 102 min dry interval. The test was carried out until 5,000 hours for the cementitious board specimens and until 2,000 hours for the coated steel specimens.

2.3 Salt spray test and cyclic corrosion test

A neutral salt spray test was performed based on IS0 9227[8]. 28 cycles of treatment shown in Figure 2 was also done in the cyclic corrosion test after 60 hours of sunshine carbon arc irradiation. The both corrosion tests were performed for the coated steel specimens with intentional scratched marks.

Neutral salt spray test at 30℃ for 30 min

↓

Wet condition at 30℃, 95%RH for SO min

↓

Drying with hot wind at 50℃ for 120 min

↓

Drying with wind at 30℃ for 120 min

1 Cycle for 6 hours x 28 repetition

Figure 2 1 cycle of treatment for the cyclic corrosion test.

2.4 Outdoor exposure tests

Outdoor exposure tests have been conducted in the 4 locations (Sapporo, Tsukuba, Kawasaki and Okinawa) for the coated cementitious specimens and in the 2 locations (Tsukuba and Kawasaki) for the coated steel specimens. The specimens were mounted on the exposure racks facing the south at an angle of 30 degrees. The tests have been continued for a few years until now.

2.5 Test painting work for repairing

Repair painting was carried out for deteriorated textured coating on fiber reinforced cementitious boards. The deteriorated textured coating specimens (sized 180 cm x 90 cm) listed in Table 3 had been exposed for 14 years in Tsukuba. Extensive chalking and partial peeling and checking could be observed on the exposed specimens, however, bonding strength of the old layers to the substrate was not so low as initial bonding strength. The new coating systems in Table 3 were applied on these old coating layers after cleaning with water at the pressure of 15 MPa. The top coating layers in all the old textured coating systems were partially removed after such treatment and repainting work was conducted on the old coating layers including the partial old top coating layers.

Table 3 Repair coating specification for exposed textured coatings on the cementitious boards.

Coating system	Top coat of the old coating systems	New coating system	
		Under coat	Top coat
System J	solvent type polyurethane	water-based sealer	water-based fluoropolymer
System K	solvent type polyurethane	solvent type sealer	solvent type fluoropolymer
System L	water-based acrylic paint	water-based sealer	water-based fluoropolymer
System M	water-based acrylic paint	water-based sealer	water-based acrylic paint
System N	solvent type of acrylic paint	water-based sealer	water-based fluoropolymer
System 0	solvent type of acrylic paint	solvent type sealer	solvent type polyurethane

Preparation of old coatings: water cleaning with pressure at 15MPa

3 Results and Discussion

3.1 Acceleration test

Figure 3 shows the changes in gloss values at 60 degrees' reflection with carbon arc irradiation time for the coated cementitious boards. The results for the coated steel specimens showed similar behavior with Figure 3. As shown in the figure, it was confirmed that the water-based fluoropolymer paints kept about 90 % of their initial gloss up to 5,000 hours' irradiation and their resistance against ultraviolet light is competitive with that of the solvent type of fluoropolymer paints reported previously[2],[3]. This high durability is considered to be primarily due to strong bonding energy between C-F bonds. On the other hand, the controlled polyurethane paints and the acrylic paints lost their initial gloss remarkably with the irradiation time.

Table 4 shows the results of visual inspection after the salt spray test and the cyclic corrosion test. One of the important results was that System E did not possess enough corrosion protective performance. In System E, bonding performance to the substrate is considered to be insufficient due to insufficient performance of under coat.

To improve System E, addition of a process of middle coating with a water-based paint (System F) or use of a solvent type of paint as under coat (System G) is necessary.

System H and System I are rather popular as anti-corrosive coating specifications for heavy duty protection. Although the slight blistering could be observed in the cyclic corrosion test, the both systems showed good performance in total.

As to the anti-corrosive coating systems using water-based fluoropolymer paints, it can be said that such systems are as good as the coating systems using the polyurethane paints or solvent type of fluoropolymer paints if the under coating systems are sufficient. To improve the performance of under coats, addition of a middle coating process with a water-based paint or use of a solvent type paint for under coating is necessary.

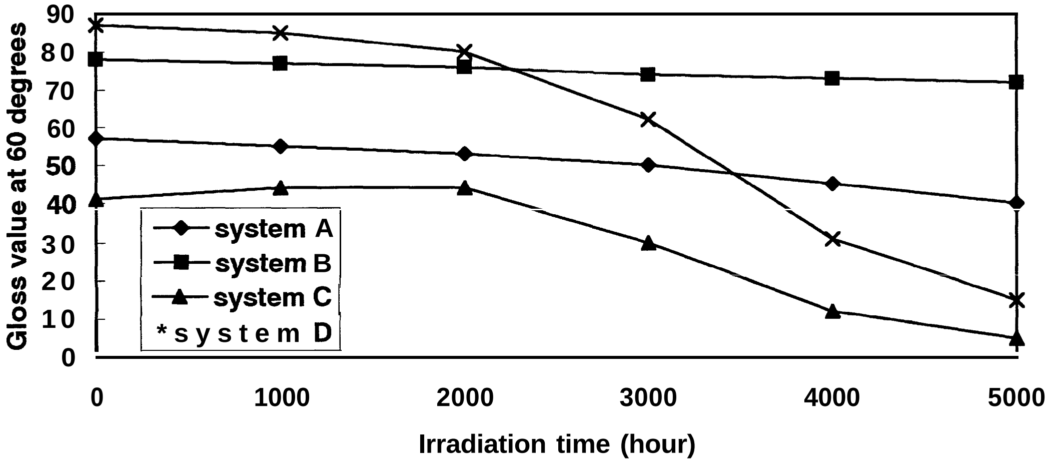

Figure 3 The changes in gloss values for the coated cementitious board specimens.

Table 4 Results of the salt spray test and the cyclic corrosion test.

Coating system	Cross-cut test before corrosion tests	Visual inspection after salt spray test	Visual inspection after cyclic corrosion test
System E	poor (10/25)	rusting within 120 hours	color change
System F	good (25/25)	no change more than 500 hours	no change
System G	good (25/25)	no change more than 500 hours	no change
System H	good (25/25)	no change more than 500 hours	slight blistering
System I	good (25/25)	no change more than 500 hours	slight blistering

3.2 Outdoor exposure test

Measurement of color difference and gloss has been performed periodically in the outdoor exposure tests. Figure 4 shows the changes in gloss retention after washing with water for the coated cementitious specimens exposed in Okinawa located in southern part of Japan. As shown in the figure, the specimens coated with the water-based fluoropolymer paints and the solvent type of fluoropolymer paints keep high gloss retention percentages. On the other hand, the specimens coated with the water-based acrylic emulsion paints and the solvent type of polyurethane paints are significantly losing their initial gloss. The outdoor exposure tests in other places showed similar results with the results obtained in Okinawa.

The results obtained in the outdoor exposure tests are consistent with the results obtained in the sunshine carbon arc irradiation test. The outdoor exposure tests are to be continued until the data after 10 years will be obtained.

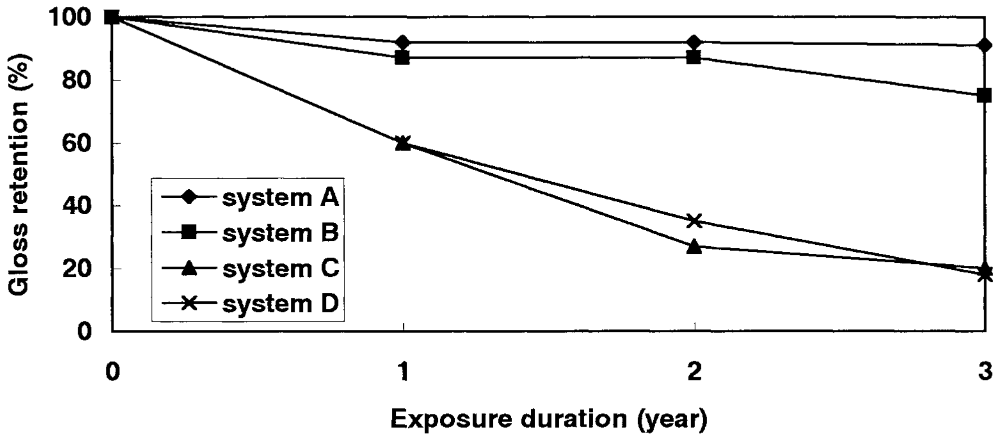

Figure 4 The changes in gloss retention after washing with water for the coated cementitious board specimens exposed in Okinawa area.

3.3 Applicability for repair coating

The repaired coating with the specifications listed in Table 3 was successfully conducted in every specification. The failures due to incompatibility with the existing coated layers such as delamination and swelling of the old coated layers could not be observed in and after repainting. The repainted specimens have shown no deterioration phenomena except for natural loss of the gloss until now. Moreover, adhesive strength to the old coated layers was confirmed to be sufficient by a pull-off test and a cross-cut test.

Generally speaking, water-based emulsion paints are preferable for repair coating to avoid swelling the old layers. On the other hand, adhesive performance to old coated layers are generally not so good as that of solvent type of paints. For this reason, the adhesive strength of the specimens are planned to be checked periodically in future.

4. Conclusion

A series of performance evaluation tests for newly developed fluoropolymer emulsion paints were conducted. It is considered that the durability of the water-based fluoropolymer paints is as high as that of organic solvent type of fluoropolymer paints.

Through these tests, a draft of useful coating specifications with water-based fluoropolymer paints could be obtained both for new construction and for repair works. The obtained draft of the specifications is helpful for application of the water-based fluoropolymer paints, although it will need to be reviewed based on the further data.

5. References

1. Sakamaki, F. (1986) Hydrocarbons in the Global Troposphere, *Res. Rep. Natl. Inst. Environ. Stud., Jpn., No.* 102, pp. 31-42.
2. Motohashi, K. and Miyazaki, N. (1987) Durability of Coating Materials Made of A New Type of Fluoropolymer Cured at Room Temperature, *Proceedings of the 4th International Conference on Durability of Building Materials & Components,* Vol. 1, pp. 317-324.
3. Motohashi, K. and Sakai, Y. (1993) Performance Evaluation of Newly Developed and Highly Durable Coating Materials, *Proceedings of the 6th International Conference on Durability of Building Materials & Components,* Vol. 2, pp. 724-733.
4. JIS (Japanese Industrial Standard) K 5658-1992, Fluoro resin paint for architecture, Japanese Standard Association.
5. JIS (Japanese Industrial Standard) K 5659-1992, Fluoro resin paint for steel structures, Japanese Standard Association.
6. JASS (Japanese Architectural Standard Specification) 18 (1989) Paint Work, Japanese Architectural Institute.
7. IS0 4892-4:1994, Plastics - Methods of exposure to laboratory light sources - Part4: Open-flame carbon-arc lamps.
8. IS0 9227:1990, Corrosion tests in artificial atmosphere - Salt spray tests.

Returnable packaging for non-specific building materials

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Abstract
A certain amount of construction waste comes from disposable packaging and this waste is ecologically damaging, one solution would be to reduce the disposable by using returnable packaging for non-specific construction products. To find out if this solution is feasible a study has been carried out on the economical and ecological consequences.
A housing construction project was chosen to get insight into the sizes of the construction products and in the amount of packaging used in the construction products. Based on these results a transportation system has been developed. First an inventory was made of all the functions needed in the transportation system. For every function a solution is developed, and for the functions together, a principle design was chosen.
This study led us to design a synthetic crate with the floor dimensions of 400 by 600 and 400 mm height, and a lid which can be used as a small pallet. The crates are transported to the building site on EURO-pallets and are manually handled into the building by a specially designed handcart. The handcart has the functions of a pallet-cart, wheel barrow and sack car.
To manage these crates, lids and pallets a pool system was also designed. The principle of this system is that the pool organisation buys the crates and lends them to the packers with a deposit. The packer pay a fee to the pool organisation to can fill a crate. The transportation firm gets paid from the pool organisation for bringing back the empty crates to the packers. Based on this system, calculations are made on what the fee should be.
The use of the crate is economically and ecologically more interesting for construction products which use a high proportion of disposable packaging.
What important is in introducing a returnable crate is an efficient pool organisation. The packers must be the owners of the pool organisation.
The returnable crate is not only interesting for the environment, but it also has advantages for the working circumstances and the logistics between the producers and users of building materials.
Key words: Environment technology, packaging, return systems, transport equipment, waste prevention.

1 Introduction

The building of residential houses and non-resident buildings in 1993 in the Netherlands resulted in between 7,4 - 9,6 million ton waste [1]. Seven percent of this waste consists of disposable packaging materials [2]. The waste is transported from the building site to the recycling industry, dumping-ground or waste burning installations. The last two ways of getting rid off the waste are damaging to the environment.
The government says that there is a priority on what to do with the waste: first prevention, then re-use, burning and dumping. The government stated also that in the future packaging material has to be re-used for 66% [3].
A returnable packaging for building materials could be a solution that is in line with the government policy: it avoids the use of disposable packaging and encourages re-cycling because returnable packages can be re-used.
The idea using a returnable packaging is not new, other industries and shops are already using it.
Is the returnable packaging for non-specific construction products economical and ecological feasible? To find out this question a study on the order of the Ministry of Housing and Environment had been carried out.
This article will show the method and the results of this study [4].

2 Housing project

To develop a returnable packaging for non-specific building materials, insight into the number and sizes of these materials is necessary. To get these sizes and the number of the building materials, a housing construction project was chosen to measure these data. The housing project consisted of 27 houses which will be sold to the residents.
Some materials were not measured. These are materials which are liquid or delivered in bulk, which have extreme weight and dimensions, and which are already mounted in prefab products. This leaves 288 materials with a volume of 1026 m^3.
All the data is put into a spreadsheet, so that selections and calculations can be made.

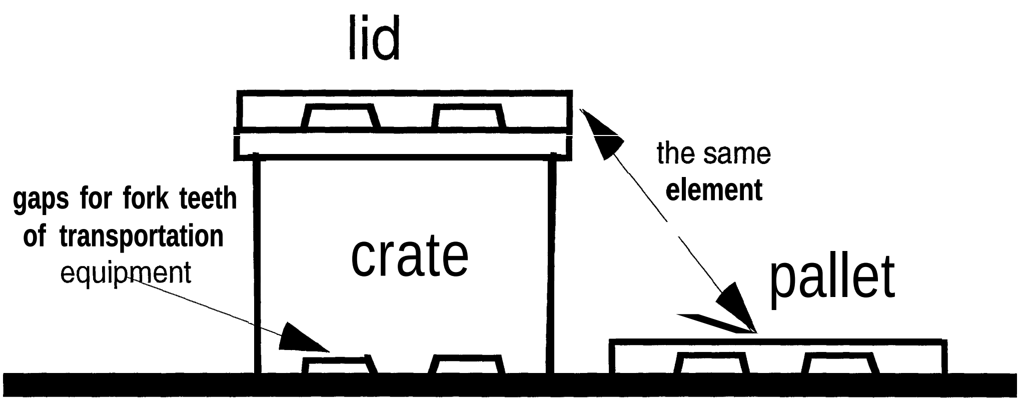

Figure 1 *Crate with lid.*

3 Transportation system

Based on these results a transportation system has been developed. First an inventory was made of all the functions needed in the transportation system. For every function a solution is developed, and for the functions together, a principle design was chosen.

This principle design is engineered to 'function models' of:

- A crate of re-cycled Poly Ethylene 400 by 600 mm ground floor and 450 mm inner height. The lid of the crate can be used as a small pallet. See Figure 1 for a sketch of the crate and lid. Eight crates can be transported to the building site on one EURO-pallet. The crates and lids can be stapled two layers height on the pallet in different ways. See Figure 2 for some possibilities. The empty crates can be nested to transport them with a minimum on volume.
- A handcart which can handle the crates from the EURO-pallet to the processing place in the building. The handcart has the functions of a pallet-cart, wheel barrow' and sack car. Figure 3 shows a 'function model' of this handcart.

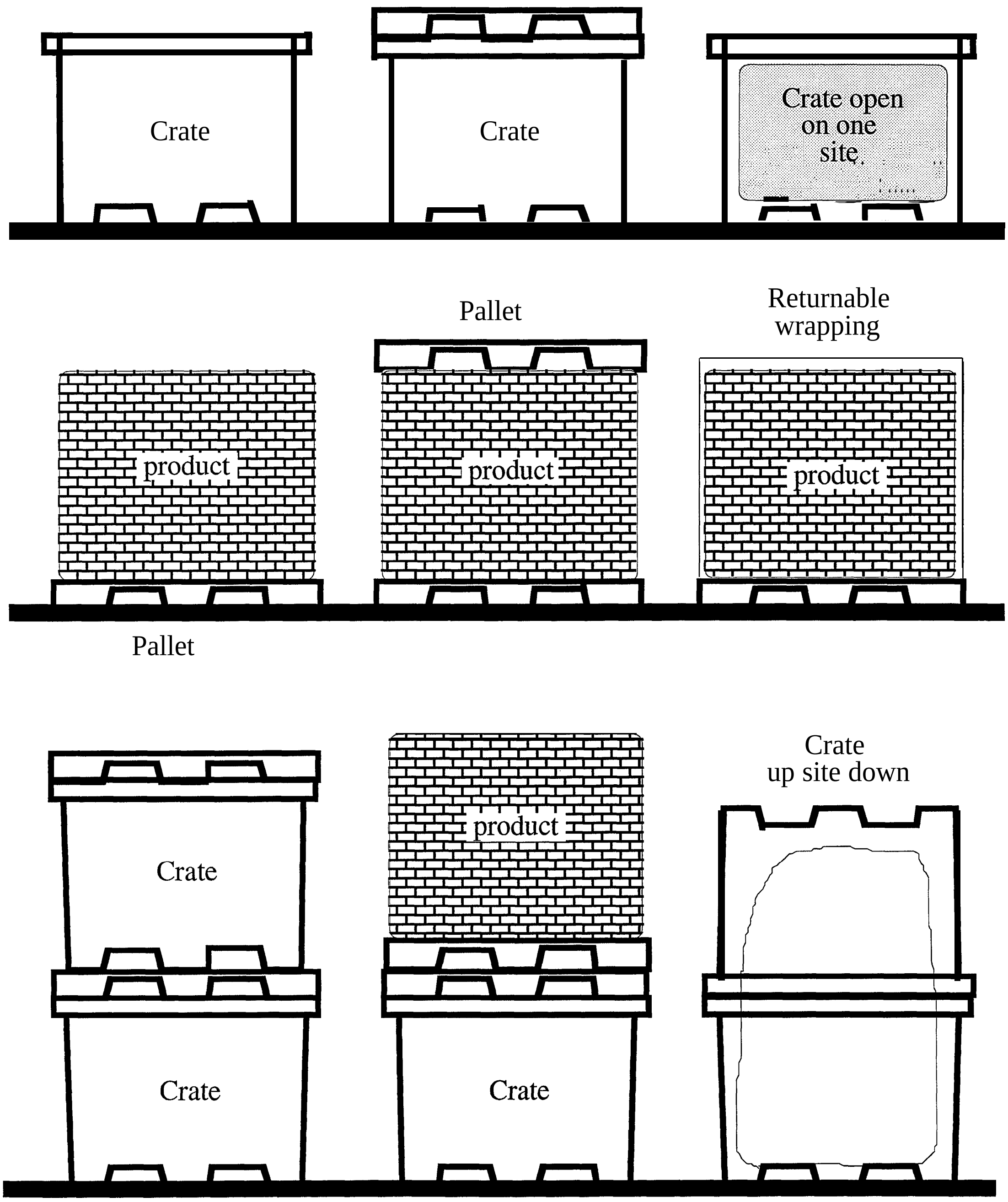

Figure 2 *Staple possibilities of the crate.*

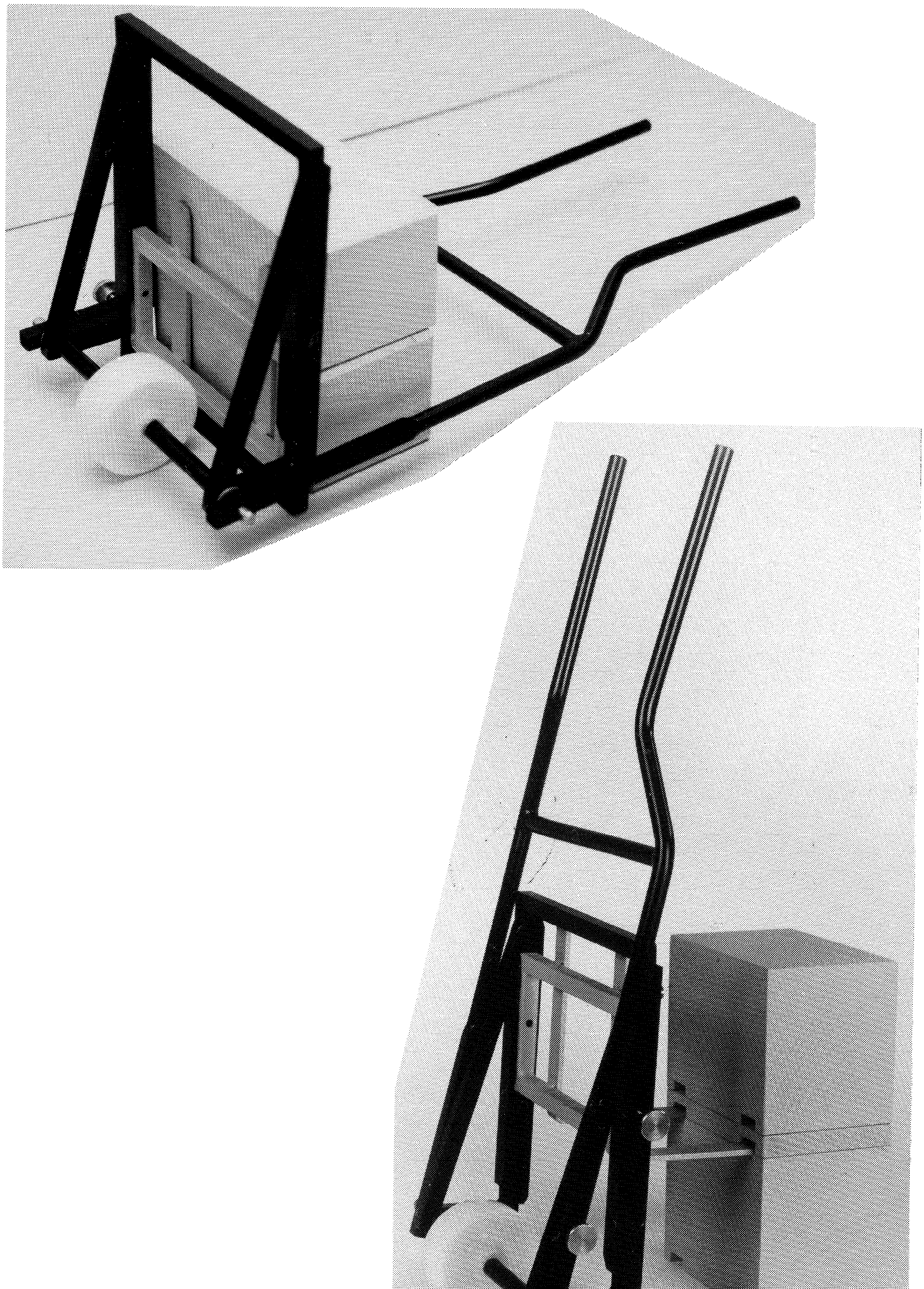

Figure 3 *Handcart as pallet-cart, wheel barrow and sack car.*

4 Pool system

To manage and to handle the return of the crates, a pool system is necessary. This system has the following partners:

- the producers of the crates, pallets and transportation equipment
- the producers of the building materials (packers)
- the transportation firms
- the trading firms of building materials (unpackers and packers)
- the contractors (unpackers)
- the pool organisation.

Every partner has a specific task and interest in the pool system. The packers are the owners of the pool system.
Two flows in the pool system are important: the money flow and the crate flow.
Figure 4 shows these flows.

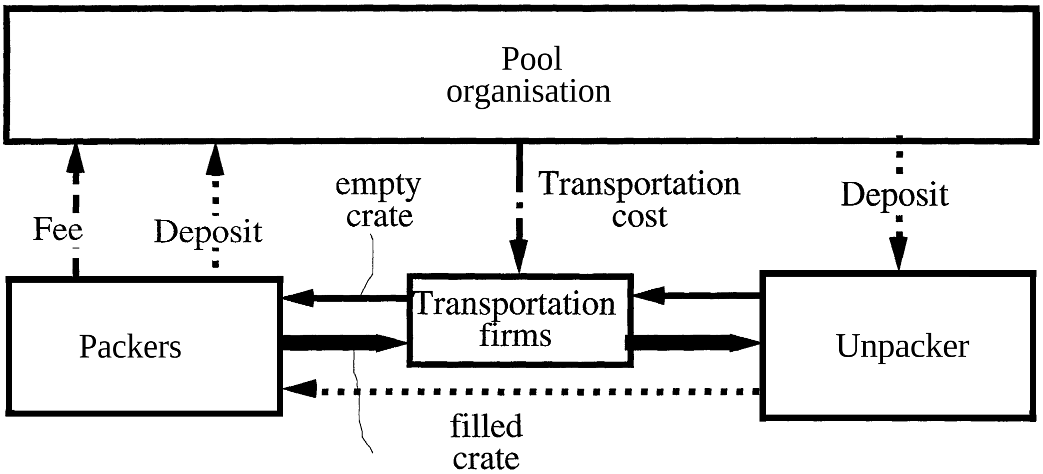

Figure 4 *The money flow and the crate flow.*

The principle of the system is that the pool organisation buys the crates and lends them to the packers with a deposit. The packer pay a fee to the pool organisation to can fill a crate. The transportation firm gets paid from the pool organisation for bringing back the empty crates to the packers. Based on this system, calculations are made on what the fee should be.
The calculation model has the following inputs:

- buying price of EURO-pallet
- buying price of crate with lid
- life of the pallet and crate with lid
- demolition cost
- maintenance cost
- interest
- deposit amount
- the number of filled crates on the pallet
- lost and damaged
- average transportation distance
- the number of empty crates on the pallet
- the number of pallets on the truck
- cost loading and unloading of pallets
- cost of administration and organisation pool
- the number of crates on stock by the packer
- stacking cost
- cleaning

5 Results

To find out if the developed transportation and pool system is economical and ecological feasible a study had carried out with the next results.
Some calculations have been made to study the economical feasible. The result is that the packer of the construction products pays a fee of HFL 1,22 per crate with lid to the pool organisation and has self about HFL 0,43 cost for storage and cleaning the crates.
Looking at the housing project we calculated that from the 175 products which can be packed in the crates 142 (8 1%) products give economical advantage to use the crate. In volume this is 33 m^3 on 672 m^3 (4,9%). The economical advantage for the contractor of the housing project is HFL 428 and for the packer HFL 1175. The advantage for the constructor increases as the cost to get rid off of the waste increases. The calculations stated that the use of the crate is no economically interesting by construction products which are delivered in great amounts and with limited disposable packaging. Such construction products are bricks and tiles.
The ecological feasibility is calculated with the Eco-indicator[5]. The result is that the value of the Eco-indicator for disposable packaging is 1,67 mPt and from the crate is 0,56 mPt. The lower this value, the better it is for the environment.

6 Discussion

In the building industry returnable packaging is already used; dry mortar in silos and window glasses in steel frames. EURO-pallets are also used on the construction sites but have problems with the paying of the deposit and the return transportation costs. The use of a returnable crate on the construction site is new. What important is in introducing a returnable crate is an efficient pool organisation. The packers must be the owners of the pool organisation. Also important is to normalise the transportation system for a broad acceptance.
The returnable crate is not only interesting for the environment, but it also has advantages for the working circumstances and the logistics between the producers and users of building materials.
To make the returnable crate successful in the short term it already can be used between the dealers of construction products and the contractors.

7 References

1. *Praktijkboek Bouw- en sloopafval*, november 1996, TenHagenStam uitgevers, Den Haag.
2. Groot, F. de, *Kostenbesparing tot 5%*, BouwWereld nr. 22, 17 oktober 1995.
3. *Packaging Covenant,* The Minister of Housing in the Netherlands.
4. Gassel, F. van , *1996, Returnable packaging for non-specific building materials,* Eindhoven University of Technology, Eindhoven, UCB -report (in Dutch).
5. Goedkoop, M., *De Eco-indicator* 95, Rapport NOVEM, nummer 9510, 1995.

A Proposed Standard for Service Life of Buildings: Part 3 Auditing Systems

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Abstract
Durability and service life are vitally important and crucial issues to sustainable building development. This paper outlines the synopsis of Part 3 of the proposed ISO standard concerning auditing systems for service life planning of buildings. This work has been initiated by the ISO/TC 59/SC 14 "Design Life" and is a supporting document to the first part of the standard (Part I, General Principles). It describes a systematic procedure to audit durability and service life in planning design and maintenance of a building. The auditing systems will enable the client to review all ownership implications concerning durability and service life in the proposed building design. Finally, it gives a base for the research needed to formulate supporting documents needed for the implementation of this standard.
Keywords: Auditing systems, durability, service life, standards.

1 Introduction

It is a well known fact that the construction industry and the built environment are main consumers of resources – materials and energy. The stock of buildings and infrastructures is growing in all countries and built environment normally constitutes more than one half of their real capital. Construction represents up to one quarter of the GNP in many countries of the world.

Recent attention worldwide has highlighted the need for the constructions industry to cut its costs significantly and to improve its effectiveness. For example in the UK a figure of 30 % has been proposed by a joint government/industry review. Such savings can only be achieved by significant improvements in current practice . One major improvement would be the ability to design buildings for a specified design life [1].

The European Construction Products Directive in force in the EU sets out six essential requirements for works which must be satisfied during an economically reasonable working life [2], [3], [4]. Technical specifications for building products prepared by CEN and EOTA must contain provisions for assessing the products service life.

The international standards organization (ISO) in co-operation with the European Committeee for Standardization (CEN) has focused this area and in 1993 initiated the IS0 TC59/SC3/WG9 group which aims to the development of international standards and guidelines for the service life planning of buildings. This group is now upgraded to an own subcommittee ISO/TC59/SC14, Design Life.

The proposed IS0 standard [5], [6] contains five parts addressing:

- Part 1: General Principles
- Part 2: Service life prediction methods
- Part 3: Auditing systems
- Part 4: Data formating
- Part 5: Life cycle costing and maintenance

The different parts of the standard are expected to be completed for submission as Draft International Standard (DIS) as follows:
Part 1 in 31 March 1998
Part 2 in 31 October 1998
Part 3 in 31 March 1999
Part 4 in 31 March 1999
Part 5 in 31 December 2000

2 Aims

The purpose of the work presented here is to:

- To outline a synopsis aiming to identify the level of the audit reviews to be undertaken for the service life profile and design approach as described in Part 1, General Principles, of the proposed standard for design life of buildings.

3 Synopsis of Part 3, Auditing systems

The following documents have been reviewed for this synopsis:

- Methodology for technical audit of building and component durability - draft 3, dated November 1997. Prepared by Building Performance Group Ltd. or the Defence Estates Office
- Initial notes on scope for Part 3 prepared by Dr. Wyatt of University of Brighton, dated 30 January 1996
- Rough draft synopsis of Part 3 prepared by Mr Cain of Defence Estates Office, dated 10 January 1997
- Durability Brief and Durability Audit prepared by Mr Marsh of BRE for Durability by Intent for Concrete programme, dated 26 November 1996
- Notes on scope of Part 3 by working group at meeting of TC59/SC3/WG9 on 28/29 May 1997

3.1 Introduction

- cross references to other parts of IS0 15686 introduction to contents of Part 3
- references to IS0 9000 / IS0 14000
- concepts in service life planning and auditing overview diagram(s)
- limitations of Part 3 / caveats as required indication of role of auditing Scope

3.2 General audit issues

- introduction to actors / roles
- explanation of stages in auditing
- introduction to reporting audits and audit levels training / skills / liabilities of auditors quality assurance and quality control of auditing

3.3 Auditing the brief - to include:

- parties
- need for record of client requirements for service life record of client requirements for service life suggested proforma
- explanation of headings within proforma
- guidance to auditors and others on changes in requirements guidance to auditors on reporting on clients requirements references to documents which may help in compiling clients requirements
- guidance for auditors on missing criteria within the record of clients requirements

3.4 Auditing the design phase

- overview of design phase audit
- references to Part 1
- structure of design audit (building type, elements, components) targeting design audit to high risk areas

- proforma for auditing design
- explanation of sections within proforma
- identification of component design lives and maintenance/construction requirements/ assumptions
- guidance to auditors on assessing service life of components guidance to auditors on relevant subjects such as environmental
- assessments, interfaces / assemblies, interpretation of data on service life, warranties etc.
- references to documents which may help in auditing design guidance to auditors on reporting design audit

3.5 Auditing the construction phase

- overview of construction phase audit references to Part 1 procurement review - to include references to IS0 9000 structure of construction audit
- targeting construction audit to high risk areas proforma for construction audit
- explanation of sections within proforma
- identification of construction below levels assumed in design audit changes in design or construction during the construction phase commissioning of building and building services
- references to documents which may help in auditing construction guidance to auditors on reporting construction audit

3.6 Reporting the audit

- introduction
- audit levels / scope of audit report
- advanced notices / early warnings during audit evidence of audit trail
- contents of audit reports at various levels / times interpretation of audit reports
- response to interim audit reports
- response to final audit report
- proforma for audit reports (written and graphical interpretations) brief section dealing with use of databases, expert systems etc.

4 Acknowledgements

The authors of this paper appreciates many helpful suggestions by and discussions with Dr. David Wyatt at the University of Brighton, UK who is the chairman of the drafting committee for Part 3 of the standard. Thanks are also due to Mr C. T. Cain, Ministry of Defence, UK who has supported this work closely. Finally, many thanks are due to Mr. A. Raphael Makenya for helping us with the editing of this work.

5 References

1. Soronis, G. (1992) The problem of Durability in Building Design. *Construction and Building Materials*. 1992, 6.
2. Caluwaerts, P., Sjöström, Ch and Haagenrud, S. E. (1996) Service life Standards – background and relation to the European Construction Products Directive. Durability of Buildings Materials and Components, *Proceedings of the Seventh International Conference in Stockholm*, Sweden, E&FN Spon, London, UK.
3. Frohnssdorff, J. G. and Martin W. J. (1996) Towards Prediction of Building Service Life: The Standards Imperative. Durability of Buildings Materials and Components, *Proceedings of the Seventh International Conference* in Stockholm, Sweden, E&FN Spon, London, UK.
4. Bourke, P. K. (1996) Model for Insuring Durability of Building Components, Durability of Buildings Materials and Components, *Proceedings of the Seventh International Conference* in Stockholm, Sweden, E&FN Spon, London, UK.
5. Browne, R. D. and Soronis G. (1996) A proposed IS0 Standard for the Service Life of Buildings: Part 1, General Principles. Durability of Buildings Materials and Components, *Proceedings of the Seventh International Conference* in Stockholm, Sweden, E&FN Spon, London, UK.
6. Soronis G. (1996) Standards for Design Life of Buildings: Utilization in the Design Process. *Construction and Building Materials*. 1996, vol. 10, no. 7.

A discrete stochastic model for performance prediction of roofing systems

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Abstract
A stochastic modeling of the performance of roofing components and systems is proposed using a discrete Markov chain that predicts the incremental deterioration of roofing components. The capability to predict the performance of roofing-components and systems throughout their service lives is essential and constitutes the first step towards the development of a comprehensive building envelope life-cycle asset management system. The proposed Markovian model allows the simultaneous consideration of the time-dependence and randomness of the performance of roofing components and systems taking into account the uncertainty and variability associated with material properties, environmental degradation factors, quality of workmanship, and maintenance conditions. Depending on the controlling explanatory variables, transition probability matrices are generated for roofing components and systems using in-field performance data obtained from inspections. This probabilistic model can then be coupled to an optimization algorithm for the development of a risk-based optimal maintenance management system for roofs at both project and network levels.
Keywords: Condition rating, deterioration, Markov chain, performance, roof system, roof components, service life, stochastic process.

1 Introduction

Low-slope and more specifically built-up roofing systems are and have been extensively used in the North American building industry. For example, the volume of work in built-up roofing constructed in 1995 in the USA rose to 18.35 billion dollars (US) of which 79.1 % was comprised of low-slope roofing [1]. Similar statistics regarding the extent of use of low-slope roofing were derived from a survey undertaken by the Canadian Roofing Contractors Association (CRCA); it indicated that well over 56% of the roofs constructed in 1993 were built-up-roofing (BUR) [2]. Premature roof failures are nonetheless common place and the associated costs of repair can be a substantial portion of the yearly maintenance budget, especially in large single-story industrial buildings. Preventative maintenance strategies for roofs are increasingly being used to help mitigate these harmful effects. Nevertheless, without well established methodologies for verifying the in-service performance and expected remaining service life of the roof, the risk of failure and the consequences of premature roof deterioration cannot be readily ascertained using the existing maintenance methods.

In an industry-wide survey of built-up roofing membranes, it was found that no type of roofing membrane had more than a 50% probability of lasting 20 years [3]. The main causes of roof failures are water ponding, untested new materials, membrane splitting, water vapor condensation within the roof due to insulation use, membrane blistering, and leakage or destruction of the insulation due to vapor barrier use [4].

The performance of a roof system and its components deteriorates with time due to aging effects such as aggressive environmental factors, excessive loads as well as poor workmanship and lack of maintenance. The uncertainty and variability associated with these deterioration factors result in considerable fluctuations of the performance and service life from the mean values. Therefore, a realistic predictive model of roofing system performance should be time-dependent and probabilistic.

In this paper, a stochastic modeling of the performance of roofing components and systems using a discrete Markov chain is proposed. A Markov chain is a discrete stochastic process that enables the simultaneous consideration of the time-dependence and uncertainty of the system performance. This approach has been widely applied to solve different time-dependent probabilistic problems [5,6,7]. This probabilistic performance prediction model for low-slope roofing systems and their components constitutes the first step towards the development of an effective building envelope life-cycle asset management system (BELCAM) [8]. The development of the BELCAM system includes the following phases: (i) Collection of roofing performance data from in-field inspections and grouping according to material and roof system type, geographical location, and building type; (ii) Generation of transition probability matrices and development of Markovian models; (iii) Assessment of the risk of failure for different roofing systems and building types, and; (iv) Development of a risk-based life-cycle roofing maintenance management system.

2 Performance of built-up roof components and systems

A modern built-up roof system has in general five basic components, namely a waterproofing membrane, thermal insulation, flashings, structural deck and possibly a vapor or air barrier [9-10]. There is a strong correlation between the performance of different components, which in turn has a direct impact on the performance of the entire roofing system and its risk of failure. Generally speaking, two types of roofing configurations can be identified depending on the location of the membrane, namely: (i) Conventional roofing system in which the membrane is at the top and is directly subjected to environmental stresses, and; (ii) Protected or inverted membrane roof system in which the membrane is protected from environmental stresses by the insulation. In the following section, a brief description of the degradation mechanisms of various components is given. The performance requirements of a roofing system can be summarized as follows [9-10]: (i) *Water tightness:* prevention of water leakage into the building; (ii) *Heat transfer control:* prevention or minimization of heat (or cooling) exchange between the interior and exterior; (iii) *Condensation control:* prevention of water vapor condensation within the roof system; (iv) *Load accommodation:* ability to sustain dead and live loads, and; *(v) Maintainability:* capability of economic repair.

2.1 Failure modes of roofing components

- *BUR waterproofing membrane:* The built-up roofing (BUR) membrane is predominant on low-slope roofs and is manufactured by adhering three or more felt plies to each other with hot bitumen. BUR membranes are reinforced with organic, asbestos or glass-fiber felts. The service life of BUR membranes increases with the number and strength of felt plies, and as mentioned earlier, no type of roofing membrane had more than a 50% probability of lasting 20 years [3]. It was also found that due to a considerable scatter in the life data of these roofing systems, a normal distribution was used to approximate their service life [3]. The main degradation factors are temperature, solar radiation, water and wind. The major modes of failure are blistering, splitting and ridging. Slippage, delamination, alligatoring and surface erosion are less widespread [4]. Blisters, and to a lesser extent splitting, are the most common distress affecting BUR membranes. Splitting is the most serious failure mode and occurs more frequently in cold climates, more often on large roof areas. The causes of splitting include thermal contraction, insulation movement, water absorption in felts, and deck deflection.
- *Thermal insulation:* It reduces heating and cooling costs and has become an indispensable component of roofing systems for occupied buildings given the rapid increase of energy costs. The thermal resistance of the insulation depends on the performance of the vapor barrier and membrane, and its effectiveness is seriously compromised by moisture. Notwithstanding its positive attributes, the insulation may increase the probability of membrane splitting and water vapor condensation within the roof system. The presence of moisture in the insulation is the result of either condensation or water penetration through defects in the membrane and flashing. Moisture reduces the thermal performance of insulation and this reduction is a function of the material type.
- *Flashings:* They seal the joints at vertical elements, curbs, chimneys, vents, expansion joints and wherever the membrane is either interrupted or terminated. Base flashings are a continuation of the BUR membrane at the upturned edges, while

counterflasings shield the exposed joints of the base flashings. Flashings are considered to be the most common source of roof leaks [4]. The basic failure modes of flashings include [4]: Sagging, ponding leakage, leakage around (through) the flashing, separation of flashing materials, diagonal wrinkling, and post-construction damage.

- *Vapor / air barriers:* A vapor barrier is used to prevent the water vapor condensation within the roof system. The air barrier is used to minimize air leakage through the roof system [9].
- *Structural deck:* It provides structural resistance to the sustained dead and live loads and transmits the loads to the roof framing. The failure modes of a roof deck include excessive deflection, cracking (concrete deck) under service loads and flexural and shear failures under ultimate loads.

2.2 Reliability of roofing systems

The roof system is a multi-component system with multiple failure modes that can be modelled as a hybrid system that is a combination of series and parallel subsystems. The probability of failure of each roofing component is time-variant and increases with time due to the time-dependent degradation of its performance. The probability of failure can be determined using systems reliability approach taking into account the correlation between different components and failure modes. In addition, the corresponding risk of failure of the roofing system could be evaluated once the consequences of failure are established. Two types of failures can be identified: (i) Envelope failure defined by the loss of the envelope main functions (loss of water tightness and energy control), and; (ii) Structural failure (outside the scope of this paper), defined by the deck failure that includes collapse and loss of serviceability. The risk of envelope failure should be kept below a certain threshold value, which depends on the value and vulnerability of the building contents under the roof, costs of repair and other incurred costs.

3 Existing approaches to roofing performance prediction

The prediction of the performance or service life of a roofing system and its components is a very complex problem as it depends on several factors including the loading, environment, quality and frequency of maintenance, quality of materials and workmanship. Despite the large number of publications related to durability and service life prediction of building materials and components, there is a lack of reliable and practical quantitative approaches to performance and service life prediction of materials, components and systems. Moreover, the existing systematic methods, including accelerated testing [11], have yet to be successfully applied to roofing systems.

Accelerated testing is carried out by imposing higher than normal stress levels on building components in order to increase the rate of degradation and thereby shorten the component life. The purpose of such testing is the generation of performance or lifetime data in a short period of time, thus overcoming the time and money constraints associated with field exposure tests. Such data are analyzed by fitting a degradation model to the data to estimate the relationship between performance, age and stress level. The principal objective is the determination of the relationship between failure time and stress magnitude (of degradation factor) in order to extrapolate to actual in-service stress magnitudes. The main accelerating stresses used to increase the deterioration process of BUR roofing membranes include temperature (60°C to 150°C), ultraviolet radiation, water and mechanical stress [10]. Although accelerated testing can be useful in ranking the performance of different roof materials or components, it suffers from many shortcomings [12, 13], which include: (i) Difficulty to simulate the degradation mechanisms of the various materials and their interaction; (ii) Difficulty to reproduce the stochastic nature of the degradation factors affecting the roof performance, and: (iii) Difficulty to correlate accelerated laboratory test results to the actual in-service results.

Given the time-dependence, large uncertainties and correlation of the performance of roofing components, a stochastic model is proposed in this initial research stage and is described in the following section. At a later stage when considerable performance data are collected, simplifications may be made to derive practical semi-probabilistic approaches to performance and service life prediction of roofing systems.

4 Markov chain modeling of roofing system performance

In this paper, a stochastic modelling of the performance of roofing components and systems is proposed using a discrete Markov chain. This model forecasts the future performance of roofing components and systems throughout their entire service lives. This performance prediction capability is essential for the development of an effective roofing maintenance management system. The Markovian prediction model represents an important class of stochastic processes with wide engineering applications (queuing, inventory and maintenance models) [5,6,7] This model takes into account the randomness of performance and its time-variance. The roof component (or system) performance is not a deterministic quantity but rather presents a large scatter, which is due to the variability of material properties, degradation factors, workmanship and maintenance conditions. The performance deterioration may be the result of excessive environmental conditions (temperature, water, moisture, wind), poor materials and workmanship and inadequate maintenance. In addition, there is in general a strong correlation between the performance of the different roofing components (membrane, insulation, flashing, vapor barrier, deck). The combination of the above may result in different and complex degradation mechanisms with cumulative damage effects. These irreversible damages accumulate until the component reaches a threshold performance level that defines failure of the component or system. The service life of the component or system is defined as the time corresponding to this minimum performance level.

In this paper, condition ratings are used as a quantitative measure of the performance of roofing components and systems. Seven integer ratings are adopted to estimate the performance of the membrane, insulation, flashing, and deck, with 7 and 1 representing the "excellent" condition and "failed" conditions, respectively as shown in Table 1. The use of condition ratings for the assessment of facility performance is very widespread given their practicality and cost-effectiveness as they allow the development of optimal maintenance management strategies. They constitute an integral part of various maintenance management systems used for different facilities, including bridges, pavements, and roofs [7,12]. The initial condition ratings of the roofing components are estimated from in-field inspection and evaluation of the **type,** quantity and severity of distresses, by a procedure similar to that used in "ROOFER' [12].

Table 1. Condition assessment of roof components and systems

Condition	Excellent	Very good	Good	Fair	Poor	Very poor	Failed
Deterioration	None	Negligible	Low	Medium	High	Major	Extensive
Rating	7	6	5	4	3	2	1

The Markov chain is a stochastic process whose state space is finite or countable, that may be described by: $\{S(t_m) = s_k, k = 1, 2, 3, 4, 5, 6, 7\}$, such that the probability of a future state of the system, $S(t_{n+1})$, at time t_{n+1} is governed solely by its present state $S(t_n)$ at time t_n, and not its entire history, i.e.:

$$P[S(t_{n+1}) = s_j \mid S(0) = s_k, S(t_1) = s_{k-1}, \ldots, S(t_n) = s_i] = P[S(t_{n+1}) = s_j \mid S(t_n) = s_i] = p_{ij} \quad (1)$$

The transition probability p_{ij} represents the likelihood that the condition of a roof system will change from state i at time t_n to state j at time t_{n+1}. Equation (1) indicates that the conditional probability distribution of any future state $S(t_{n+1})$ is independent of the previous states, $S(t=0)$, $S(t_1)$,..... $S(t_{n-1})$, and depends only on the present state $S(t_n)$. This assumption represents the first-order type of stochastic process correlation underlying the Markovian process [6]. The states 7, 6, 5, 4, 3, and 2 are called transient states, whereas state 1 is called an absorbing state, which is a state that cannot be vacated, once entered if no repair is made. The Markovian modeling of the performance requires only limited data on the condition of the roofing system (or components) at two or more points in time, in order to derive the probabilities of transition from one state to other states having lower condition ratings.

The performance of different roofing systems and components is dependent on several explanatory variables, including age, environmental conditions, material and system types, loading magnitude, workmanship quality and maintenance level. In order to validate the adopted Markov chain model, it is necessary to develop transition probability matrices for roofing components and systems according to their classification with regard to the above explanatory variables. A stationary stochastic process may be assumed which implies the time-invariance of the transition probability matrix. The transition time is generally taken as one year, but other time intervals can be chosen depending on the time between consecutive inspections. Given the adopted condition rating scale and short transition time, the probability of a roofing component decaying by more than one state in one year may be assumed negligible. As a result, the performance of a roofing system (or its components) of a certain class can be modeled using the following transition probability matrix:

$$\mathbf{P} = \begin{vmatrix} p_{77} & p_{76} & 0 & 0 & \ldots\ldots\ldots\ldots & 0 \\ 0 & p_{66} & p_{65} & 0 & \ldots\ldots\ldots\ldots & 0 \\ & & & & & \\ \cdot & \cdot & \cdot & \cdot & \bullet \; p_{22} & p_{21} \\ 0 & 0 & 0 & 0 & \ldots\ldots\ldots\ldots & 1 \end{vmatrix} \quad (2)$$

in which p_{ij} is the probability of transition from state i to state j in one step or transition time. Hence, the transition probability matrix is greatly simplified and consists only of two terms in each row, namely: p_{ii}, and p_{ij} ($p_{ij} = 1 - p_{ii}$), representing the probability of remaining at the same state and that of deteriorating by one state in one transition period, respectively. Each drop in the condition rating may correspond to a different degradation mechanism. The Markov chain modeling and the associated transition probabilities for a deterioration process are illustrated in Fig. 1, for a roofing component or system with the seven condition states defined in Table 1.

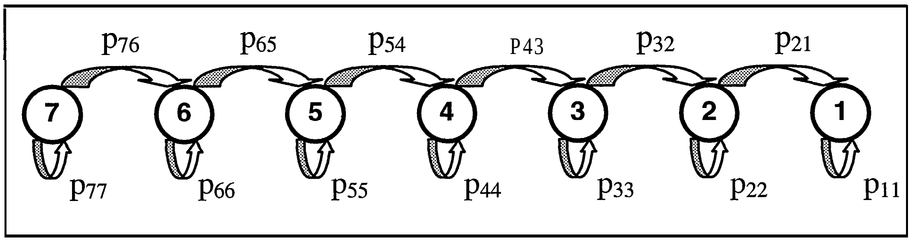

Figure 1 Markov chain modelling of roofing performance deterioration (with no repair)

Once the one-step transition probability matrix is generated, the future performance of a roofing component can be predicted using the n-step transition matrix as follows:

$$\mathbf{P}\{S(t_n)\} = \mathbf{P}\{S(0)\}\mathbf{P}^n \tag{3a}$$

which can be written in the following simplified form :

$$\mathbf{P}(n) = \mathbf{P}_o\mathbf{P}^n = [p,(n),\ p_6(n),\ldots,\ p_1(n)] \tag{3b}$$

in which $P\{S(t_n)\} = P(n)$ is the state probability matrix at time t_n after n transitions; $\mathbf{P}\{S(0)\} = \mathbf{P}_o = [p_7(0), p_6(0), \ldots, p_1(0)]$ is the initial state probability matrix; P is the transition probability matrix; and $p_k(n)$ and $p_k(0)$ are the probabilities that the component is in state k at times $t = t_n$ and $t = 0$ (initial condition), respectively.

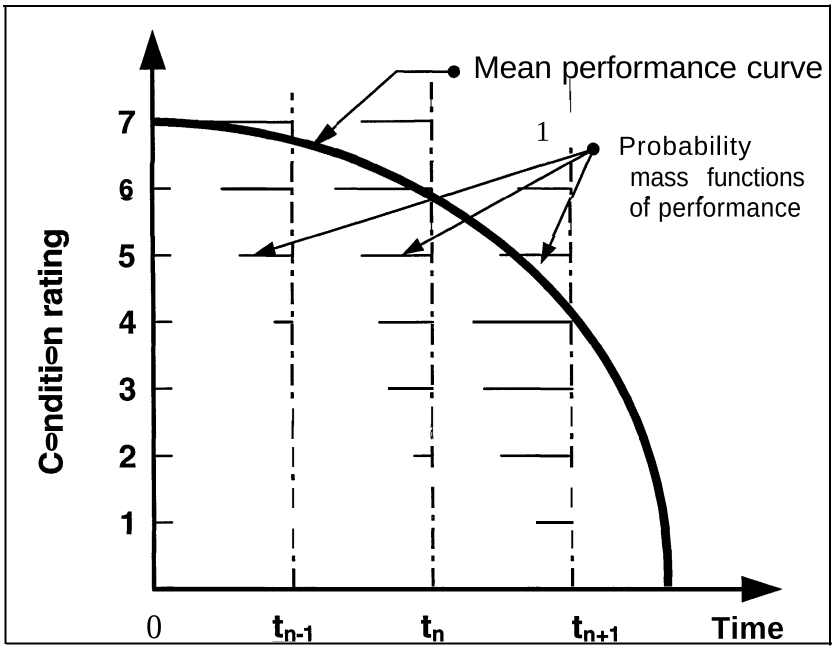

Figure 2 Markov chain prediction of roofing system performance

The probabilistic prediction of the performance using Eq. (3a) is illustrated in Figure 2, which indicates the evolution with time of the probability mass function of roofing performance. In general, at the start of the roof service life, the probability mass is close to condition rating 7; after aging and deterioration, this probability mass shifts from states having high condition ratings to those states with lower condition ratings. Ultimately, if no repairs are made, all the probability mass accumulates in the absorbing state with a condition rating 1. The transition probability matrix is determined as the solution of the following nonlinear programming problem, where the objective function is the minimization of the difference between the performance data obtained from in-field inspections and Markov chain predictions, i.e.:

$$\min \quad \sum_{k=1}^{7}\sum_{n=1}^{N}[p_k(n) - p_k^*(n)]^2 R(n) \qquad (4a)$$

$$\text{subject to:} \quad 0 < p_{ii} \le 1 \qquad (i = 1, 2, \ldots\ldots 7) \qquad (4b)$$

in which $p_k^*(n)$ = relative frequency of components in state k at age n from inspection data; $p_k(n)$ =Markov chain prediction of probability of being in state k at age n, obtained using Eq.(3b) as a function of p_{ii}, (i = 1, 2, ...,7); N= number of inspections or years of available data; and R(n) = number of components at age n.

The underlying assumption of the first-order Markov chain model referred to as the "Markovian property" is the dependence of the rate of deterioration on the current stress and cumulative damage and not on the entire stress history. The validity of this property will be checked through statistical inference testing. The transition probability matrix can be further updated using the Bayesian technique if additional performance measurements become available. The development of this Markovian model will be based on condition data of roofing components and systems collected throughout Canada using "ROOFER' [12] as a data acquisition system, in which many roofs, (grouped according to their age, material type, geographical location, and operating conditions) will be inspected at two or more points in time.

5 Conclusions

This paper illustrates the possibility of modeling the performance of roofing envelope systems using a discrete Markovian stochastic process that takes into account the time variance and randomness of this performance. The transition probability matrices for roof components and systems will be derived using in-field inspection data, for roofs grouped according to the controlling explanatory variables. This probabilistic modeling of performance enables a rational evaluation of the actual risk of roof failure that depends on the probability of failure of the entire roof system (membrane, insulation, flashing, and vapor barrier) and the consequences of this failure. The consequences of roof failure depend on the cost of repair, value and vulnerability of the building contents under the roof, and cost of disruption. This time-dependent probabilistic model constitutes the first phase towards the development of an effective risk-based roofing maintenance management system at either project- or network-levels that minimizes the life-cycle cost of the roof including the costs of maintenance, repair, replacement and failure.

6 References

1. Kane, K., (1996) NRCA's Market survey indicates business was better than expected, *Professional Roofing* 26(3), pp. 16-20
2. Anonymous (1995) CRCA conducts roofing survey, *Canadian Roofing Contractor*, July, pp.23-26.
3. Cash, C.G. (1980) Durability of bituminous built-up roofing membranes, in: *Durability of Building Materials and Components*, American Society for Testing and Materials STP 691, Sereda, P.J, and Litvan, G.G. eds., pp. 741-754.
4. Griffin, C.W. (1982) *Manual of Built-up Roof Systems.* 2nd Ed., McGraw-Hill.
5. Bogdanoff, J.L., and Kozin, F. (1985) *Probabilistic models of cumulative damage.* J. Wiley & Sons, New York.
6. Ross, S.M. (1996) *Stochastic processes,* J. Wiley & Sons, 2nd Ed., New York.
7. Saito, M. (ed.) (1997) Infrastructure condition assessment -Art, science, practice, *Proc. ASCE Conference,* American Society of Civil Engineers, Boston.
8. Vanier, D.J., and Lacasse, M.A. (1996) BELCAM project: service life, durability and asset management research, in: *Durability of building materials and components 7,* V.2, pp.848—856.
9. Baskaran, B.A. (1996) Roofing systems and their performance requirements, in: *Building Better roofs,* NRCC/IRC Seminar, 20p.
10. Cash, C.G., and Bailey, D.M. (1993) Predictive service life tests for roofing membranes: Phase 1. *USACERL Interim Report FM-94/03*.
11. ASTM E632 (1988) Standard practice for developing accelerated tests to aid prediction of the service life of building components and materials, *American Society for Testing and Materials,* V4.07, ASTM, West Conshohoken, USA.
12. Bailey, D.M., Brotherson, D.E., Tobiasson, W., and Knehans, A. (1989) ROOFER: an engineered management system (EMS) for bituminous built-up roofs. *USACERL Technical Report M-90/04.*
13. Masters, L.W. (1987) Service life prediction: a state of the *art,* in: *Durability of building materials and components, Singapore,* pp. l-9.

Multicomponent cementitious binder from industrial by-products

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Abstract

Over hundred million tonnes of industrial by-products namely flyash, phosphogypsum, fluorogypsum and lime sludge are produced every year from various processes in India causing unwanted pollution and health-hazards. To save ecosystem, there is a strong need for effective and proper utilization of these by- products in the building sector. Keeping this in view, cementitious binders have been produced by blending fly ash with the calcined phosphogypsum or fluorogypsum and lime sludge. The cementitious binders produced using the ground fly ash ($400 m^2/kg$, Blaine) gave compressive strength of 25-27 MPa at 90 days. The strength was further enhanced on addition of cement.

The durability of cementitious binders has been studied by long term performance of the hardened binder in water and by wetting and drying cycles at 27° to 50°C. One cycle of wetting and drying comprised of heating the cubes for **16** hours at different temperatures followed by cooling for one hour and immersion in water for 7 hours. An increase in water absorption and porosity was observed with the increase in curing period. The formation of hydraulic products such as ettringite ($C_3A\ 3\ CaSO_4.32H_2O$), C-S-H and wollastonite which are responsible for hardening of the cementitious binders and their durability were identified by differential thermal analysis and scanning electron microscopy. The cementitious binders are eminently suitable for use in masonry mortars and concrete.

Keywords : Binder, flyash, phosphogypsum, ettringite, durability

1 Introduction

Over 100 million tonnes of waste material are produced as by- product from various agro-industrial processes in India per annum. These materials have degraded the environment and posing a threat to human and animal life. The utilization of by-products like fly ash, phosphogypsum, fluorogypsum, lime sludges and other materials are of paramount importance due to their enormous availability causing disposal and pollution problems. These materials have been used to small extent because of presence of certain undesirable impurities in them.

Extensive work has been carried out at Central Building Research Institute, Roorkee to develop a variety of building materials out of several solid industrial wastes. Some work on the utilization of these wastes has been reported elsewhere [1]. To save environment, it is necessary to develop useful building materials from them. With this objective, investigations were undertaken to produce cementitious binders by blending the fly ash with calcined phosphogypsum, fluorogypsum, lime sludges, Portland cement with and without chemical activators. The physical properties of these binders and the data obtained on their performance in water and the durability studies conducted by wetting and drying cycles at different temperatures are reported in the paper. The hydration of the binders as monitored by differential thermal analysis and scanning electron microscopy are also discussed. The suitability of newly synthesised cementitious binders for making masonry mortars and cement concrete has been examined and the findings are reported.

2 Methodology

The industrial wastes such as fly ash, phosphogypsum, fluorogypsum, lime sludges and the Portland cement conforming to relevant Indian Standards were collected from the indigenous chemical plants and the cement factory for their use as raw material.

The cementitious binders were prepared by blending the raw materials i.e. fly ash (as such - 300 m^2/kg, ground - 400 m^2/kg Blaine), calcined phosphogypsum (β-hemihydrate, 320 m^2/kg Blaine), calcined hydrated lime sludge (320 m^2/kg, Blaine), Uncalcined fluorogypsum (3 10 m^2/kg, Blaine), portland cement (325 m^2/kg, Blaine) and a chemical activator (passing 150 micron IS sieve) in different proportions (Table 1) followed by grinding in a ball mill to a fineness of 330 m^2/kg (Blaine). These binders were tested for their various physical properties as per IS:403 1- 1989 [2]. Hydration studies of experimental binders at normal consistency were undertaken by differential thermal analysis (Stanton Red Croft, London), and scanning electron microscopy (SEM Model 508, Holland).

The durability of cementitious binders was examined by their performance in water and by the alternate wetting and drying cycles at 27 to 50°C by immersing the hardened binder cubes (2.5 cm) in water for evaluating their behaviour. One cycle of wetting and drying was comprised of heating the cubes for 16.0 hours at different temperatures followed by cooling for one hour and immersion in water for 7.0 hours [3]. The compressive strength and change in weight of cubes was measured.

The mortar making properties of the binder was studied using binder and sand (F.M. 1.82) in the proportions 1:1, 1:2, 1:3, 1:4 and 1:5 by weight at 105 + 5% flow as per IS:4031-1989. The concrete cubes were cast as per IS:516-1991 [4] using 10.0 and 25.0 percent replacement of Portland cement by the cementitious binder, Badarpur Sand

(F.M.2.2) and gravel in the proportion 1:2:4 at water cement ratio 0.50. The strength and water- retentivity of mortars and concrete mixes were determined.

Table 1

Mix composition of cementitious binder based on industrial wastes

Mix designation	Mix composition (wt%)					
	Fly ash	Calcined *PG	Fluoro-gypsum	Portland cement	Lime sludge	Chemical Activator
1. (a)	70	15	---	---	15	---
[b]	70	10	---	---	20	---
[c]	65	10	---	---	25	---
2. (a1)	60	15	---	20	5	---
3. (a2)	Binder 1 (b) 90	---	---	10	---	---
4. (a3)	65	---	15	---	20	---
5. (b3)	60	---	10	15	15	1

* PG : Phosphogypsum

3 Results and discussion

3.1 Properties of cementitious binders

The properties of cementitious binders are reported in Table 2. It can be seen that the consistency and setting time reduced while the compressive strength increased of binders produced from the ground fly ash and other ingredients than the cementitious binders produced from unground fly ash etc. The increase in strength can be attributed to the decrease in the consistency and the increase in the formation of hydraulic products formed during the progressive curing period. The formation of hydration products are graphically illustrated in Figure 1. for the binder (b) and (a2). The endotherms at 5 10°-520°C, 620°C, 790 and 960°- 980°C are due to $Ca(OH)_2$, fly ash, wollastonite and $CaCO_3$ respectively. Whereas intensity of gypsum endotherms at 160°- 170°C decreased and that of ettringite ($C_3A.3CaSO_4.32H_2O$) at 150°C increased. The small endotherm at 130°- 135°C on low temperature flank of ettringite is due to C-S-H. The endotherms obtained for decomposition of $Ca(OH)_2$ and $CaCO_3$ reduced and that of C-S-H compound (790°C) enhanced in the ground fly ash binders than the unground fly ash binders confirming their contribution in the overall increase in the strength. The formation of typical hydraulic products such as subhedral to anhedral needles of ettringite, hydrated plates of C-S-H and wollastonite and the partially hydrated fly ash spheres found in case of binder (a2) are shown in Figure 2.

Table 2

Properties of cementitious binders based on industrial wastes

Mix Designation	Consistency (%)	Physical' Properties					
		Setting Time (Hrs)		Compressive Strength (N/mm^2)			
		*I	*F	3d	7d	28d	90d
With unground flyash							
1 (a)	39.1	2 0	5.0	1.65	2.18	10.5	19.61
(b)	37.8	0.57	3.12	1.85	3.07	12.19	19.60
[c]	38.0	0.54	3.03	2.05	2.94	9.70	14.45
2. (al)	34.7	0.42	2.42	6.91	9.92	25.90	30.0
3. (a2)	37.7	1.88	3.40	3.40	6.90	16.0	24.76
4. (a3)	34.6	24.0	6.80	0.92	2.05	11.0	17.53
5. (b3)	34.7	4.5	7.0	5.36	8.16	15.23	25.45
With ground fly ash							
1 (a)	31.1	0.39	3.50	2.98	7.28	16.70	26.68
(b)	31.0	0.35	4.55	4.07	7.85	18.40	21.73
[c]	34.4	0.40	3.22	4.40	6.86	15.04	22.19
2. (al)	29.3	0.38	1.32	9.80	14.94	26.40	32.04
3. (a2)	30.0	0.35	1.90	7.62	13.94	20.50	32.04
4: (a3)	32.7	3.90	6.60	3.51	5.65	13.30	34.22
5. (b3)	30.0	4.20	6.0	14.12	16.50	23.41	34.20

* I : Initial, F : Final

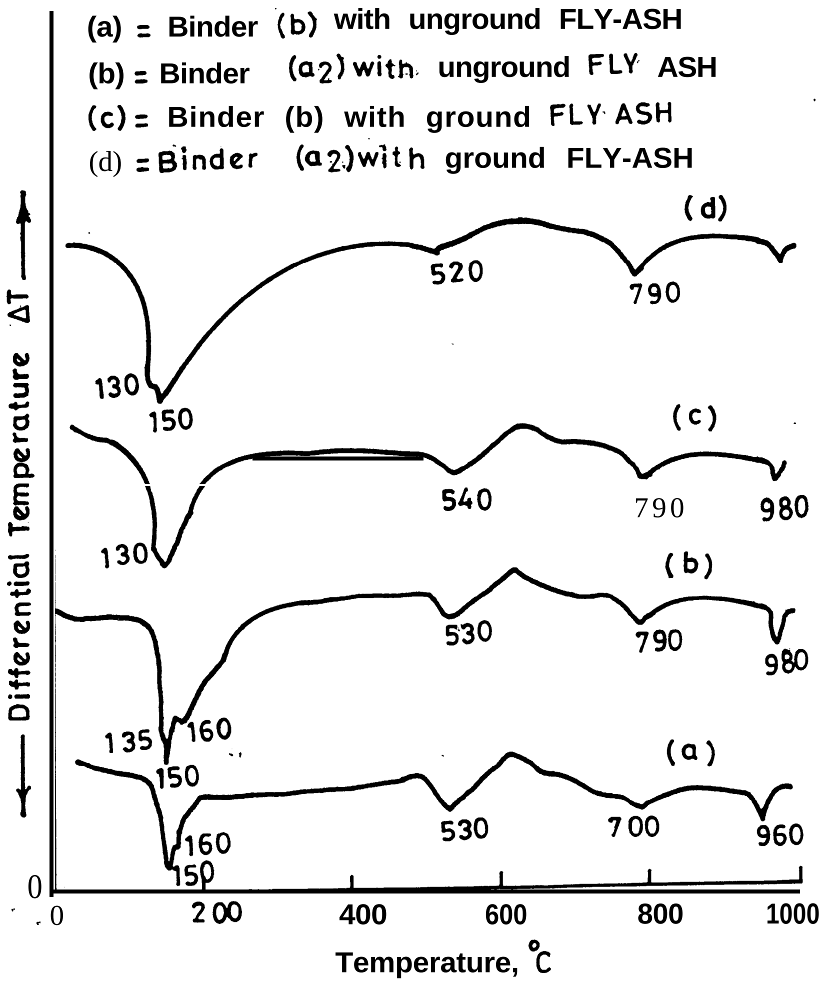
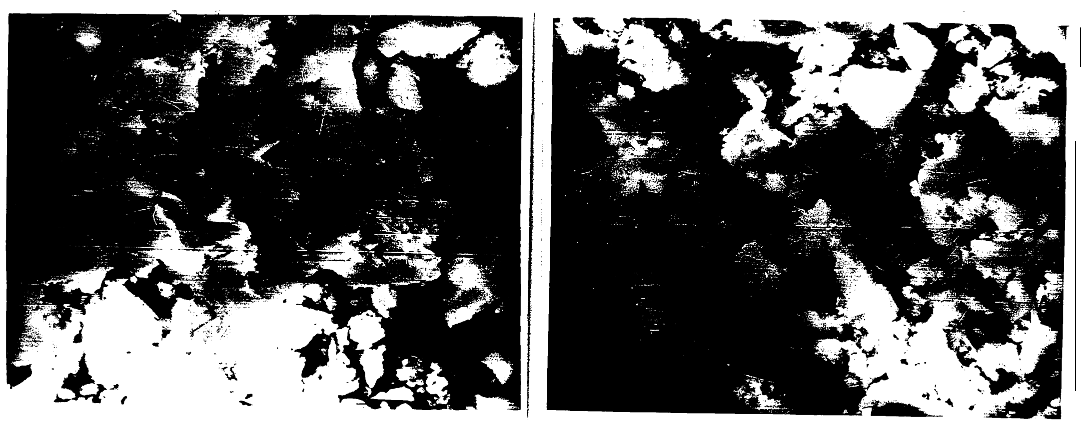


FIG. 1

Differential thermograms of cemkntitious binder hydrated for 90 days



(a) (b)

FIG.2

Microphotographs of hydrated binder a.2 at (a) **7** days and '(b) 28 days (x 1250)

3.2 Durability of cementitious binders

The performance of the cementitious binders was studied by immersion of 2.5 cm cubes of cementitious binder (28 days cured) in water. Data showed that the porosity and water absorption increased with increase in the immersion period without leaching etc. The absence of leaching of the binders confirm their increased level of stability towards water, hence water- resistance. On subjecting the cementitious binders to wetting and drying cycles from 5 to 50 cycles at 27°, 40°C and 50°C, variation in strength development was found due to variable hydration of the binders. The residual strength at 50 cycles was detected higher than the pristine strength in case of binders based on the ground fly ash due to better hydration of former than latter. However, loss in strength measured in the binders based on unground fly ash etc. was higher probably due to lower formation of ettringite and C-S-H compounds.

3.3 Use of cementitious binders in masonry mortars and concrete

The properties of masonry mortars prepared from cementitious binders (b), (al), (a2) and (b3) showed that. a mix proportion 1:4 (binder-sand) attained maximum compressive strength in the range 2.90 to 5.40 MPa at 7 days and 5.50 to 9.0 MPa at 28 days and the water retentivity of the order of 60.0 to 65.0 percent as against the minimum specified values of 2.5 and 5.0 MPa and 60.0 percent respectively laid down in IS:3466-1981[5]. These values were far better than the traditional cement-sand (1:6) mortars.

The studies conducted on the part replacement of the binder in cement concrete showed that the binder (b) can be partly replaced for the cement in the concrete mix 1:2:4:cement:fine aggregate: coarse aggregate. Replacement of cement by the binder (b) upto 10% and 25% by weight did not produce any detrimental effect on the strength of concrete,

4 Conclusions

1. The cementitious binders can be formulated by judicious blending the industrial wastes such as fly ash, phosphogypsum, fluorogypsum, lime sludges and cement together.
2. The attainment of high strength in the binders is due to the formation of ettringite, C-S-H and wollastonite.
3. The binders are quite durable as they do not show leaching of the matrix when subjected to long term immersion in water.
4. The binders are suitable for making masonry mortars and as part replacement of cement in cement concrete. The production and use of cementitious binders fi-om solid industrial wastes is strongly recommended to solve their disposal problem.

5 Acknowledgement

The work reported in this paper forms a pa of nor nal research programme at the Central Building Research Institute (India), and is published by permission of the Director.

6 References

1. Singh Manjit (1993), Use of industrial by-products in the manufacture of cements and alternative binders, Indian Cement Review-Annual `92', pp 119-128.

2. Bureau of Indian Standards, IS:403 1-1989, Specification for physical tests of hydraulic cements, New Delhi, India.
3. Kulkarni, B.N., Narain, S.N. and chandawat, B.S., (1977), Trans. of' Indian Society Desert Technology, Vo1.2, No. 1, pp 12 1.
4. Bureau of Indian Standards, IS:5 16-1991, Specification for methods of tests for strength of concrete, New Delhi, India.
5. Bureau of Indian Standards, IS:3466-198 1, Specification for masonry cements, New Delhi, India.

Service life prediction of buildings and the need for environmental characterisation and mapping

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Abstract
In the developed countries, the building stock and infrastructure constitute more than 50 per cent of each country's real capital. A large part of the building stock and infrastructure will sooner or later fall into disrepair and make the economic and the cultural costs significant due to deficient maintenance. To make the maintenance more efficient and reduce the costs there is a need to predict the service life of building components and materials. Methods for service life prediction of building components and materials have been and are developed within an International Standard (ISO). The standard is based on formulas where the length of service life can be estimated. Factors based on knowledge of degradation mechanisms and dose-response functions will be the input. One of these factors quantifies outdoor environmental impact. A considerable amount of environmental data are available from meteorological and environmental research communities, but in its present form it is not sufficient for service life prediction; data must, for example, be made applicable to the micro environment of buildings. In instances where this data does not exist, research must be carried out to produce the necessary information. It is also necessary to have a systematic knowledge of the type and form of environmental degradation agents being characterised and mapped. To produce this knowledge, an extensive service life research is required. This paper describes principles for service life prediction and discuss the need for research, mapping and characterisation of the degradation environment.
Keywords: buildings, environmental characterisation and mapping, service life prediction.

1 Introduction

The building structure is one of the most important areas in a society. In the developed countries, the building stock and infrastructure constitute more than 50 per cent of each country's real capital. To pursue sustainable development and make maintenance more efficient and reduce the costs, there is a need to predict *the service life* of building components and materials. Service life is defined as the "period of time after installation during which all conditions of a building or a building part meet or exceed the performance requirements"[1]. The construction of a new building or facility is generally expensive and may require considerable resources. Hence, building constructions play a significant role in the strive for a sustainable society. In that respect the design life must, for each component, be optimised in relation to the estimated service life of the building.

Principles for service life prediction of materials and buildings have being and are established within national and international standards organisations. For example, in certain countries, within their national standards, codes or practices, the focus is being placed on providing guides to help predict service life (e.g. Durability of buildings and building elements, products and components, British Standard 7543: 1992; Guide for service life planning of buildings, Architectural Institute of Japan, and; Guideline on durability in buildings, Canadian Standards Association CSA-5478). An international standardised methodology for prediction of service life of building materials, components and buildings is presently being elaborated in ISO/TC59/SC14 [1, 2]. The standardised methodology encompasses prediction models which rely on knowledge of degradation mechanisms and dose-response functions. Dose-response functions describe the relationship between doses of environmental degradation agents and the observed effects of degradation. In order to estimate doses, a considerable amount of environmental data on the macro/meso scale is available from meteorological and environmental research communities, however, correlation between this kind of data and the micro environment at the building surface must still be completed.

2 Principles for service life prediction and international standardisation

A methodological way to predict the service life of building materials and components, is object of standardisation in the IS0 draft "Service Life Planning – Part 2: Service Life Prediction Principles" [2], which is partially based on the RILEM Technical Recommendation "Systematic Methodology for Service Life Prediction of Building Materials and Components"[3]. A prediction according to the standard relies on establishing performance-over-time functions that describe how measured values of some chosen performance characteristic of a material are expected to vary over time. With performance-over-time functions established for the range of in-use conditions considered and agreed performance criteria, all essentials elements are known to complete a service life prediction. The methodology includes identification of required information, the selection or development of exposure programmes and evaluation methods, exposure and evaluation, interpretation of data, and reporting of results. It employs an iterative approach that permits improved predictions to be made as the base of knowledge grows. These principles are elaborated in a generic format, i.e. applicable to all types of building components, and may be used in the planning of service life prediction studies, or be the guiding document in the assessment of investigations that have already been performed. The essential steps in a prediction process are shown in Fig 1.

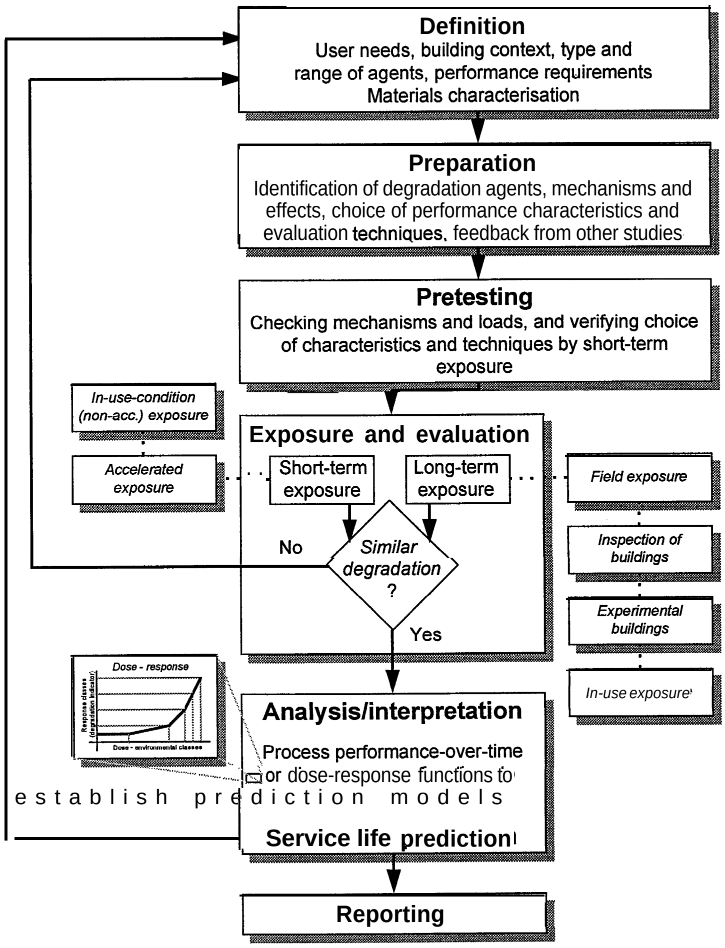

Fig 1 Systematic methodology for service life prediction of building materials and components.

A predicted service *life* of a component may be utilised as a reference service *life (RSL)*. However, the RSL is valid at the conditions employed in the study, and must be adjusted to reflect the specific conditions for a given building, thus resulting in an estimated service *life (ESL)*. This method that takes prediction data and other useful knowledge into consideration when designing a specific object - *the factor method for estimating service life* - is described in the IS0 draft standard “Service Life Planing - Part 1: General principles” [1]. The method estimates the service life using the relation:

$$ESL = RSL \times A \times B \times C \times D \times E \times F \qquad (1)$$

Thus, the reference service life for the component is multiplied by a number of *modifying factors* (A, *B, C, D*,....), each relating to a certain aspect, cf. Table 1. The environmental factor, *D,* can be divided in two parts; indoor and outdoor environmental condition. To estimate the outdoor environmental condition, the environment around a building must be characterised before the factor can be determined, since the factor is site specific.

Table 1 Modifying factors of "the factor method".

Factors related to inherent quality characteristics	A_1	Performance of Materials	Material type or grade. Manufacture, storage, transport
	A_2		Durability features: Protection system
	B	Design level	Details of construction: Joints fixing, incorporation, sheltering by rest of the structure
	C	Work execution level	Site work: Quality to standard or manufactures specifications. Level of workmanship, climatic conditions during execution work
Environment	D_1	Indoor environment conditions	Condensation,aggressiveness of environment, ventilation
	D_2	Outdoor environment conditions	Macro, meso, micro environment conditions
Operation conditions	E	In use conditions	Mechanical impact, category of users, wear and tear, vandalism
	F	Maintenance	Quality and frequency of maintenance, accessibility for maintenance

3 Environmental characterisation and mapping

The service life of a building component is, among other things, dependent on the degradation rate of the materials it is composed of. All materials will sooner or later break down. When the components are placed outdoors, the degradation rate is determined by the magnitude of environmental agents. Environmental characterisation can be provided at a general level, depending on its criticality and the data available. The classification of agents and examples of outdoor environment exposure are given in Table 2.

In principle the list follows the IS0 6241-1984 (E) standard [4] and CIB W80/RILEM140-PSL recommendation [5], describing agents relevant to building performance and their requirements. The degradation agents are classified according to their nature as *Mechanical, Electromagnetic, Thermal, Chemical* and *Biological.* This characterisation implies that the agents are listed according to their own nature and not to the nature of their action at the buildings or components; for instance, a chemical agent, such as water, may have a physical action (for example swelling) or a chemical action (for example hydration dissolution). Moreover, agents in combination may have additional physical, chemical and/or biological actions.

Table 2 Degradation agents affecting the service life of building materials and components.

Nature	Class	Example of outdoor exposure
Mechanical agents	*Gravitation* *Forces and imposed or restrained deformations* *Kinetic energy* *Vibrations and noises*	*Snow, rain and water loads, ice, formation pressure, thermal and moisture expansion, daily temperature, difference, freeze/thaw, driving rain, differential wetting or drying wind*
Electromagnetic agents	*Radiation* *Electricity* *Magnetism*	*Solar and thermal radiation*
Thermal agents	*Extreme levels or fast alterations of temperature*	*Heat and frost*
Chemical agents	*Water and solvents* *Oxidising agents* *Reducing agents* *Acids* *Bases* *Salts* *Chemically neutral*	*Water, oxidising agents (oxygen, ozone, carbon dioxide, sulphur dioxide, nitric oxide), synergistic effect of oxidising agents, acids, salts, sea spray, soot, particles, chemical incompatibility (leaching and leaches, solvents and contaminated land)*
Biological agents	*Vegetable and microbial* *Animal*	*Fungi, bacteria and insects*

As discussed above, models for service life prediction and estimation rely on dose-response functions. Some input values to these functions are doses of degradation agents surrounding the building component. At present, data on doses measured directly at a building are for the most part lacking. However, substantial amounts of environmental data are available from meteorological and environmental research communities, but this in itself is not sufficient for predicting service life; data must be transformed such that it relates to the micro environment at the surface of the building. Data have been collected at different geographical scales for other purposes. One frequently used basis of environmental classification on a geographical scale, is the division of climate into macro, meso, local and micro, as shown Fig 2 [6].

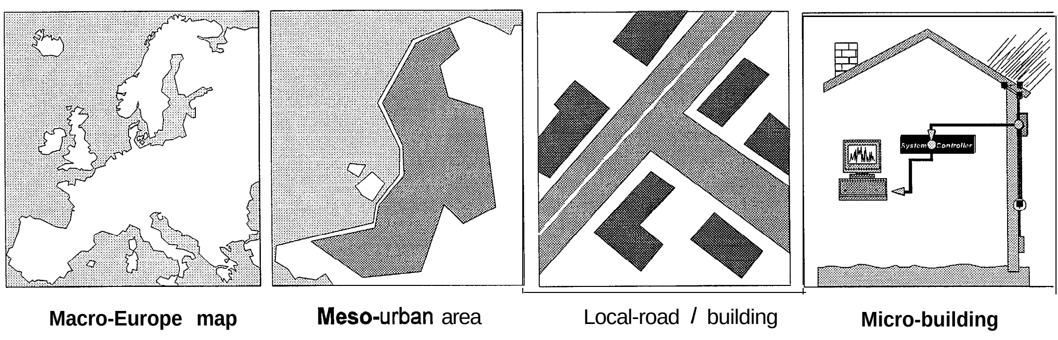

Fig 2 Exposure environment on different geographical scales.

Although at the present time there exists no common or exact definitions of the different scales, the following is now proposed: *Macro climate* represents the gross meteorological conditions described in terms such as polar climate, subtropical climate and tropical climate. When describing *meso climate*, the effects of the terrain and the built environment are taken into account in an area not exceeding 150 km^2. *Local climate* represents the local conditions in proximity to the building, for instance, in the streets around the building. The *micro climate* describes the meteorological variables in absolute proximity of a material surface. Materials' degradation takes place in the micro environment which thus makes the characterisation there of crucial to the determination of dose-response functions and ultimately - the prediction or estimation of service-life.

4 Example of environmental mapping

As previously mentioned, at the macro and meso level there are considerable amounts of data available for environmental characterisation, for example, mean values of: precipitation, temperatures, wind directions, emissions. These kinds of data can, after appropriate correction, be used for characterisation of the micro environment around a building. An example of correction factors that must be considered when transforming meteorological data from the meso level to the local and micro levels is shown in Fig 3. Methods to transform meteorological data from the meso level to local and micro level exist, for example, in standards for wind-driven rain. The driving rain index, which is a product of annual average rainfall (horizontal) and average wind speed, refer to the meso level. With a given correction factor, a value can be computed for the local and micro levels. This provides doses of water loads on vertical surfaces. Using similar methodologies, it will be possible to calculate other degradation agent doses.

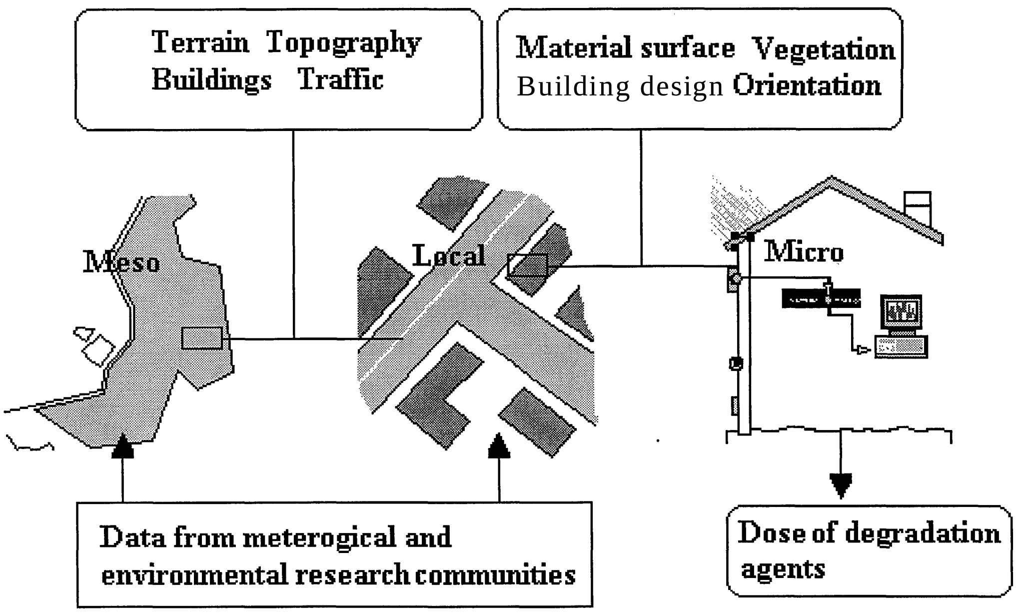

Fig 3 Correction factors to take into consideration when transforming meteorological data from the meso level to local and micro level.

In the EU-project Wood-Assess (ENV-CT950110) one of the objectives is mapping of environmental risks at the meso and micro scale. Building degradation is caused by a large variety of degradation agents. The most serious damage for wooden buildings is the rotting process. At a specific value of moisture ratio and temperature, the critical condition for the rotting process to start is reached. A well-known formula that estimates the potential of a climate to promote rotting is Scheffer's Climate Risk Index **(CRI)** [7]. The formula is based on precipitation and temperature, data that are mostly available on the meso scale. The index can be delineated in maps as geographical contours (isoploths). A problem with using the CRI in estimating the likely micro climate is the local variation in meteorological parameters for a specific building. In the Wood-Assess project one task is to compare the CRI measurements on local scale with the CRI based on data from the nearest weather station (meso scale) and the time of wetness measured in the micro environment of a specific building.

5 Conclusions

By determining the service life of building components, it is possible to reduce resource consumption, as well as reduce costs at production and maintenance of a building. An international project is focused on developing a consistent set of standardised principles for service life estimation [1]. These principles are based on a reference service life that manufactures must themselves establish, for which standardised principles also will be developed [2]. This reference service life is in a general form and has to be adjusted to the specific conditions of a construction. The adjustment can be done with factors by which the reference service life are multiplied. One of these factors is related to degradation agents in the outdoor environment. As the environment is specific for each building, a characterisation must be completed in which the degradation agents are quantified. Standardised methods for the process of characterisation still have to be created.

After that the degradation agents are characterised, a value of the factor has to be determined that relates to the environment in question. The procedure to estimate the value of this factor can, for example, be: index of each agent is taken from maps at a meso or local scale; the index is transformed with coefficients into a micro scale (i.e. the components surface); the transformed index is used as input in performance-over-time or dose-response functions, and the results from these functions are used to determine the value of the factor.

Research needs to be carried out to develop maps of indices and to estimate the coefficients for index-transformation of macro or meso to micro scale. Doses of agents causing degradation should be the basis for this index whereas the relation between data on difference scales should be the basis for determining the coefficients. Today, many of the environmental agents are measured and these data can be used to create the maps of indices. Unfortunately, data are measured only at one geographical scale (macro, meso or local). To estimate the difference between the scales, measurements must simultaneously be conducted at the micro scale. The process of developing methods for environmental dose-scale-transformation coefficients can, for example, be performed as follows: data of degradation agents are collected at the meso/local scale and the micro scale simultaneously; the relation between data (on different scales) is determined, and transferred into a general condition as coefficients, while considering transformation models.

6 References

1. International Organization for Standardization (1998) *Buildings – Service Life Planning – Part 1: General Principles,* Geneva, ISO/CD 15686-l .4.
2. International Organization for Standardization (1998) *Buildings – Service Life Planning – Part 2: Service Life Prediction Principles,* Geneva, ISOICD 15686-2 3
3. Masters, L. W. and Brandt, E (1989) Systematic methodology for service life prediction of building materials and components, RILEM, *Materials and structures,* Vol. 22, pp. 385-392.
4. International Organization for Standardization (1984) *Performance standards in building - Principles for their preparation and factors to be considered,* Geneva, IS0 6241-1984 (E).
5. Haagenrud, S.E. (1997) *Environmental Characterisation including Equipment for Monitoring. CIB W80/RILEM 140-PSL, SubGroup 2 Report,* NILU, Kjeller, NILU OR 27/97.
6. Sjöström, C. and Brandt, E. (1990) *Collection of in-service performance data: state of the art and approach by CIB W80/RILEM IOO-TSL, Proceedings of the 5th International Conference on The Durability of Building Materials and Components,* Brighton, UK 1990. Ed. by J.M. Baker et al. London, Spon.
7. Scheffer, T.C, (1970) A Climate Index for estimating Potential for Decay in Wood Structures Above Ground. *Forest Products Journal,* Vol. 21, No. 10.

Stratified Layer Building systems

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Abstract

Building in quality and respecting the environment are two big challenges of the construction world for the coming millenium. The use of *dry assembled systems* is a way to meet specific requirements for a building and, at the same time, it gives a guaranty of flexibility, as well as a possibility of disassembling and reuse or recycle of components. To optimize quality request and procedure of recycling, these systems use products of the industry assembled on site.

This paper deals with *lightweight buildings* composed by structures and addition of independent layers, choosen to give focused performances, preengineered and built on site with dry and mechanical connectors.

Keywords: Lightweight Buildings, Stratified Layer Systems, Dry Assemblies, Building Quality, Life Cycle Planning.

1 Introduction

The "now society" is characterized by very fast changes and that could be seen in many different fields of the industry: from telecomunications to informatics, from biotechnology to micromechanics. The world of constructions is for its own nature more lethargic and needs more time to get in direction of new ways of conceiving, realizing and managing its product: the building.

This concerns even more if we talk of building for housing and living in comparison with special structures where the approach is very innovative and very often a special technology, which is newly designed and requested by the big scale of these projects.

Anyway housing is the real challenge because the budgets are more restricted and that means to achieve results, in terms of quality of living and of reducing the environmental impact, in a restricted economic frame.

Very suitable 'for this appears the orientation on *dry assembled lightweight systems,* and the use of industrial products available on the market.

Conceiving *lightweight buildings* is a very new subject especially for central and southern Europe, where the construction is mainly based on monolithic systems with masonry or concrete structure. In northern Europe, Canada and USA Lightweight Buildings belong to tradition, both in wood or steel gauge frame structure, but still there are open fields also to improve these systems.

In this way the contemporary technology can be diffused for common use and gives results of quality if the products are applied following proper "new rules of the constructing art".

2 The Quality Frame

In the field of Industry the Total Quality Management has become a successful1 procedure to obtain products which will offer the consumers the expressed requirements and at the same time controlled production methods with always more attention on reducing toxic emissions.

Translating this to the building industry the subject has to deal with different steps which complicate the problem. Very often we speak about "the chain of quality" in building constructions, which could be divided in:

- Quality of Product
- Quality of Process
- Quality of Project

The *quality of product* is well defined by the standards serie IS0 9000 and the European Community Directive 89/106 about Construction Products. With these tools the producers can guaranty quality controlled products, and this means certified and with CE label [1].

The very big question is to keep the label valid in the following and complicated phases: the interaction with other materials and at least the behaviour of the product in a major entity which is the finished building. The weak points of the "quality chain" are in fact the *quality of building process* and the *quality of project and design.*

To reinforce this weakness it is possible to open a discussion about new systems to conceive and realize the building: this means quality control in all the steps of construction and new design methodologies.

Tools to obtain this could be, in the design phase, the application of the standards now under development about Service Life Planning in the Drafts of IS0 TC59/SC14 [2][3]. This could help especially if the standard is used in an interactive way with the design, giving feed-backs and guideline to realize better solutions in terms of economics, environment and quality of living.

To guaranty this and to guaranty that the *quality of product* will not be lost, during its application in following phases, an active *quality control* should be always adopted to avoid misusing and to keep a correct *life cycle planning* valid.

At least one should introduce new ways of managing the project and its realization which are possible with *stratified layer systems* [4].

3 Stratified Layer Systems

The constuction field is characterized by a lot of “actors”:

- Producers Industry
- Universities and Research Groups
- Contractors
- Workers
- Engineers and Architects

Making the technology has to be seen as an active cooperation between designers and producers [5]. This cooperation brings cultural developement for both of them, respecting the rules of codes and standards.

A real example of this cooperation is the French research circle “Architecture e Industrie” lead by Eric Dubosc, architect in Paris professor at the University of Lille, and Marc Landowski, architect in Paris and member of CSTB Consulting Committee. Their aim is to develop, together with producers, building technologies, mainly related with housing [6][7], based on *dry and lightweight buildings,* able to guaranty:

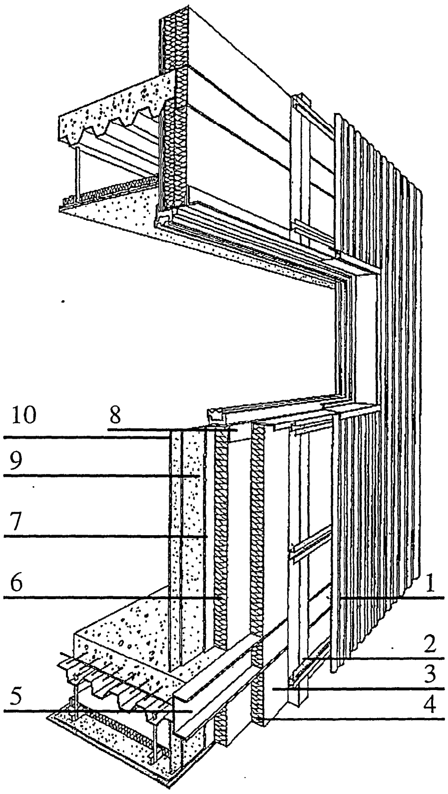
- Quality Performance at affordable price
- Use of Industrial Products
- Low Environmental Impact
- New Building Management
- Perfect Logistic and Ergotechnic

The *stratified layer systems* are conceived as separated and independent units:

1. OUTSIDE ENVELOPE
2. STRUCTURE
3. INSIDE ENVELOPE

Between these units the installations run easily accessible for cheking and eventual maintainence [8].

The primary structure, normally in steel, is a frame of beams and pillar supporting horizontal steel welded plates. The secondary structure, like a steel gauge frame [9], sustain the *stratified Layers* which are dry connected in a *sort* of *panelized system.*



Figl. Example of an outside stratified facade. La Venerie, Housing project in Montargis Le Franc, 1994 by Dubosc and Landowski.

In figure 1 we can identify, from outside towards inside, ten different layers in this composite wall :

- <u>Outside Envelope</u>
1. Coil coated corrugated steel sheet
2. Secondary structure supports
3. Air layer
4. Mineral wool for sound and thermal insulation

- <u>Structure</u>
5. Primary loadbearing structure of steel

- <u>Inside Envelope</u>
6. Mineral wool for sound and thermal insulation
7. Damp barrier
8. Secondary structure supports
9. First gypsum board layer
lO.Second gypsum board layer with finishing

Every layer is choosen and engineered to give a specific performance to the requirements expressed by the utilizer or to react to physical and chemical loads.

This means that every layer works under specific loads without interactions and gives a focused response, once we know the characteristics of inside and outside environments.

In a way the *stratified layer system* itself plays an important role for the reliability of *durability tests and prediction.* In fact the co-action of loads, like in monolithic traditional buildings, complicates the reliability of prediction based on accelerated tests or simulations.

The disconnection of the layers in *lightweight buildings* gives the opportunity to set up "Dose-Response" functions and evaluate the behaviour of a product [10], and so also the durability and the maintainance plan, with less uncertainity.

In this case the appliance of Service Life and Life Cycle Planning, Drafts of IS0 TC59/SC14, could be used as design tool based on reliable data, collected by research centers and producers, to give an active impact on the choices of appropriate material and to set up a proper maintainance plan.

4 Design for the Environment: Elasticity versus the Mass

The environmental impact of a building has to be seen in all its life cycle:

- Production
- Construction
- Operating Conditions
- Maintainance
- Reuse or Recycle, once the lifetime of a component or the purpose of the building itself is reached

Lightweight buildings are conceived as *"high environmental tech"*, because they create cycles of use. Every part of them could be substituted, reused or recycled with low consumption of energy.

Traditional monolithics buildings add more embodied energy using everlasting connections, which means use and waste of water. As a parallel the dry connections in *stratified layer systems* always allow a reversibility and demountability of the components [11]. This is a big advantage also in terms of flexibility which is a very actual request. If we notice the very fast changes coming in our life, we can also see an added value to those buildings which can adapt themselfs easier to new issues of use or maintainence.

A traditional monolithic building has a weight of 7-10 times more than a *lightweight building* to give the same performances. This means waste of energy because of transports, waste of water, materials and time which also means waste of money. The behaviour of *stratified Layer buildings* is based on elasticity properties, reacting to the physical loads by elastic deformation. Every layer is preengineered to give right performances to requirements of:

- Acoustic comfort
- Fire proofing
- Thermal and humidity comfort
- Seismic safety

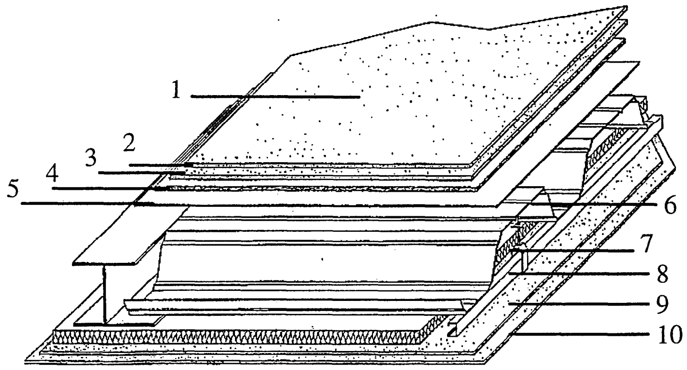


Fig2. PCIS, Plancher Composite Interactif Sec(dry composed interactive slab). Parc de Tailles, Saint Martin d'Heres, 1996 by Dubosc e Landowski.

In figure 2 is a dry lightweight floor for housing stratified, from top towards bottom:

1. Finishing carpet
2. 13 mm anhydrite panel
3. 13 mm gypsum panel
4. 12 mm glued wood panel
5. 3 mm mineral wool to cut the sound bridge
6. 2 - 420 - 200 loadbearing corrugated coil coated steel plate
7. 70 mm mineral wool for sound insulation
8. Secondary structure to hang the ceiling
9. 13 mm gypsum panel
10. 13 mm gypsum panel with finishing

The performances tested by CSTB are:

- Loadbearing surcharge: 2,50 kN per square meter; max. free span 5,8 m
- Total height. 0,32 m
- Total weight: 97 kg per square meter
- Fire: REI 30 with 13 mm gypsum boards on ceiling, REI 60 with 15 mm gypsum boards.
- Acoustic: Airborne sound insulation > 66 dB(A). Impact sound insulation < 54 dB(A); with only plastic covering: deltaL = 13 dB(A).

The system has won the "Decibel d'Or" in 1997 for its special acoustic performances, superior to the level for the label "Qualitet Comfort Acoustique".

5 Conclusions

The use of materials available on the market and industrially produced gives the opportunity to have quality products. The use of them in *dry* systems allows to reduce the uncertainity of behaviour due to uncontrollable on site elaboration which is always affected by the weather and by human errors.

With *layers systems* workers become more "high-tech artisans" and they can operate carrying light loads and working on a dry on-site.

The Architectural possibility is always left free and this plays also a role on the visual impact on the Environment without constructing buildings with the same aspect for different people and geographic frames.

Forward steps of applied research are opened in direction of integration between layers and installations. For example, to create irradiating heating and cooling systems which use low temperature aggregates and leave the possibility to use renewable energy sources like sun and geothermic energy, or creating photovoltaic cells panels to transform the house to an active energy catcher [12]. Lightweight technologies could be seen as a way to improve and develop new solutions in construction field without overloading the Environment. The application of *stratified layer systems* to methodologies proposed by IS0 TC59/SC14 (see paper in this section Hed, G., *Service Life Planning in Building Design)* could be active tools to obtain *quality buildings*, with reliable *service life predictions [* 13].

6 Aknowledgements

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7 References

1. Turchini, G., (1984) La Qualita' in Edilizia, *Management per l'Edilizia*, DEI, Roma.
2. Buildings - Service life planning - Part 1: General Principles, ISO/CD 15686 -1.4 Draft: January 1998.
3. Buildings - Service Life Planning - Part 2: Service Life Prediction Principles, ISO/CD 15686 - 2.3 Draft: February 1998.
4. Zambelli, E.,Vanoncini, P.A., Imperadori, M., (1998) *La costruzione stratificata a* secco, Maggioli, Rimini.
5. Raiteri, R. (1996) *Progettare la residenza.Tendenze innovative*, Maggioli, Rimini.
6. Imperadori,M., Poli, T., (1998) *Dubosc e Landowski. Architettura e Industria,* Grafo, Brescia.
7. AA.VV., (1996) *Dubosc e Landowski,* Korean Architects 148, KA press, Seoul.
8. Dubosc, E., (1997) *Petite Methode de Construction. Logique de chantier, Zogique de mise en oeuvre*, Carre', Paris.
9. Burstrand, H., (1997) *An efficient Industrial Building Process,* Nordic Steel and Mining Review, Stockholm.
10. Haagenrud, S.E., (1996) Management of a Durable Built Environment - a joint environmental effort, *Sustainable Use of Materials,* British Research Establishment, Garston Watford.
11. Campioli, A., (1993) *Il contesto del progetto,* Franco Angeli, Milano.
12. Herzog, T., (1996) *Solar Energy in Architecture and Urban Planning,* Prestel, Munich.
13. Sjöström, Ch., (1996) Durability and sustainable use of building material, *Sustainable Use of Materials,* British Research Establishment, Garston Watford.

Scientific tools for assessment of the degradation of historic brick masonry.

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Abstract

The aim of the research on brick masonry degradation supported by the D.G. XII is presented.

A systematized questionnaire has been conducted that allows the collection of expertise from different sources in relation to damage on historic brick masonry structures. The main initial sources are literature, data from in situ investigation carried out on historic brick masonry buildings and laboratory simulation tests. This information is collected in an **"Atlas of damage to historic brick structures"**. containing uniform terminology and a uniform description of damage types and damage origins. This information is schematized into relations between damage types, causes and the physical phenomena related to a set of deterioration processes. Particular attention is paid to the interaction between the different materials of which ancient brick masonry is composed and the effect of environmental factors.

The deterioration causes can only be understood with a knowledge of the different historic brick masonry construction types and the historic, climatical and geographic context in which those masonries have been built; used and eventually restored.

A **Masonry Damage Diagnostic System** is developed that - through systematization of this knowledge and relations - will guide the person using this expertise toward the assessment of damage type and damage cause. It also provides information on the type of investigation that has to be carried out on the masonry to be diagnosed, in order to improve the quality of the information about the damage type and damage origin. Therefore, appropriate (monument-friendly non-destructive) testing techniques are evaluated on their likelihood of increasing the precision of the diagnosis. For the creation of the expert system an expert's system shell is used based on decision tables.

The scientific methodology used for the development of both tools is given.

Key words: Masonry damage diagnostic system, expert system, historic brick structures, masonry, damage atlas.

1 Introduction.

Conservation and restoration of historic structures depend on various factors and include aspects related to different disciplines. For architectural historians involved in decision taking processes for the conservation of historic buildings the decay problem is often evaluated in a different way as by engineers or material scientists. From the other hand historical information (e.g., severe damage which occurred in the past by an accident) is a very valuable source of information if existing damage is to be evaluated.

Multi-disciplinary approach and possibility of exchange of information between different partners are hence crucial when choices between options have to be made. Diagnostic tools to evaluate the condition of brick monuments will have to take this into account.

A research group coordinated by the author developed instruments like the Masonry Damage Diagnostic System (MDDS) and a Atlas of Damages of historic brick structures which aimed at improving the diagnosis before intervention but which also can be used to evaluate previous interventions

2 Masonry Damage Diagnostic System and Atlas of damage to historic brick structures.

2.1 Objective

The objective of the project is to improve our knowledge of the effects of environmental factors on damage to Europe's cultural heritage and to guarantee better treatment and protection of our heritage, by providing the professionals who work on the analysis of ancient buildings with an expert system including a damage atlas.

2.2 Scientific approach

The aim of the project was to create an instrument bases on scientific information which could increase the number of persons to execute general monitoring of historic buildings. By increasing their number there should be a shift toward maintenance type interventions on historic buildings instead of more "heavy" restoration interventions [1]. Therefore groups of technicians, architects, engineers should be helped in executing correct analysis of the major part of (more simple) damage cases, leaving the more difficult and special cases to the smaller group of leading professionals. The latter will be thus only involved in those cases where high specialism is required. It has also been noticed that even for specialists those instruments could be a helping guide when they have to deal with fields in which they do not have very specialized knowledge. To define the group of less specialized professional (nevertheless having a broad background) the profile of the "Monumentenwachters" (Monument Watchers) of the Netherlands or in Flanders has been taken as a reference. The specificity of the scientific approach can be summarized by the following headings.

2.2.1 Multidisciplinary approach:
The approach takes into account different dimensions of the problem from material sciences, environmental sciences, biological sciences, historic sciences, architecture and urban development;

2.2.2 Complexity:
The durability of the masonry does not only depend on the behaviour of one material but on a complex interaction of different materials and different boundary conditions (e.g., traffic, pollution, precipitation, orientation, etc.);

2.2.3 Scope:
The evaluation and interpretation of damage do not so far include a proposal for treatments, but is limited to the diagnosis. It gives precise descriptions of damage types and the process responsible for this damage in the given circumstances.

2.2.4 Damage approach:
The relation between damage definition (type) and damage cause (mechanism) is based on a thermodynamical approach: resistance against stress defines the damage (function). In that respect approaching from visible damage, the process of decay is the right way to make tools that can be used for monitoring.

2.2.5 Usefulness:
The definition and terminology are based on maximum use of visual analyzing techniques and maximum collection of relevant data at the site. Additional guidance is given through testing techniques from non-destructive to destructive techniques if necessary.

2 3 **Methodology**

The methodology used is based on the scientific principles of research. In the problem stated, damage to historic brick structures, and the development of the Masonry Damage Diagnostic System defined the scientific description and deductions of the physical mechanisms causing the damage. Inherent choices have been made in relation to the order of input taken into account for the deduction: it started with the most easy way of identification which is visual analysis (this also explains the usefulness of the damage atlas) and then included in order the in situ and laboratory tests. A thermodynamical model of decay of materials as developed in the project [2] defines damage as a result of stresses and resistance allowed damage types and damage causes to be linked. This was then developed in terms of processes within the Masonry Damage Diagnostic System. The development of the Masonry Damage Diagnostic System allowed us in many cases to limit the problem only to those parameters which are described really necessary (goal oriented), thus omitting irrelevant elements while the link with the practice remains guaranteed.

This approach is unique in this field and the experience of the project demonstrated the scientific interest of this engineering approach for the evaluation of deterioration of ancient brick structures. It is an applied scientific approach producing practical results for the conservation of historic brick monuments.

2.4 Research results.

2.4.1 Terminology.

In the first stage of the work common definitions had to be set up which should be useful within the different instruments of the project. A first set of damage types has therefore been defined which is useful for the questionnaire but could be developed within the Masonry Damage Diagnostic System. The hierarchic concept allows the user to narrow his definitions gradually. This approach was based on the assumption in the project that defining goes hand in hand with increasing knowledge. Vague knowledge needs broader terms while added information has to narrow the set of terms. In the questionnaire the group of damage types is given with the subset of more precise terms. The logic in the definition was based on the visual discrimination. It has been defined so that in the order of the analysis the visual appreciation was the first "instrument" used. As the questionnaire and the related damage atlas are related to this first analysis, it was logical that the definition of damage types should use visual criteria. Within the Masonry Damage Diagnostic System the same terminology has been used while the “instrument” itself allows the user to check his interpretation of the terminology by answering questions defined by the conditions contained in the definition of the term. The structure of the terms of the damage types and definitions given in terms of conditions will be illustrated later.

2.4.2 Questionnaire.

The original questionnaire with which the project was started and which stemmed from the collaboration of the experts of the NATO-CCMS pilot study on Conservation of Historic Brick Structures has been modified considerably as described in one of the project reports [3]. The main reasons for this development are found in the interaction with the setup of the terminology which was developed in relation to the Masonry Damage Diagnostic System. Another argument was the subdivision of the questionnaire according to the order of investigation of the damage type into its possible cause. The first type of analysis is based on visual analysis and in site measurements while the second part has been made for the integration of laboratory results leading in the third part to a synthesis and an interpretation.

It was experienced that even experts contacted by purpose are hesitant to formalize the collection of information in a questionnaire if they see no direct interest or reply leading them to the diagnosis. As an instrument to monitor the questionnaire seems to have the disadvantage to be to lengthy, not precise and synthetic enough. This seemed very discouraging but it was realized that in fact this event proved the advantages of the Masonry Damage Diagnostic System. It has therefore been concluded that the questionnaire should be developed electronically. So that the user, after giving some basic information on the building and according to the previous answers he has given, is requested to answer only those questions which are relevant to the problem, which is what the Masonry Damage

Diagnostic System does. The latest version of the questionnaire itself became simpler and has been developed with a view to the rapid collection of the necessary data related to pictures for the damage atlas.

It was also seen that in practice very few professionals and owners are willing to deepen the diagnosis with laboratory tests and even with tests in situ. It is the experience of most of the partners in the project however that in many cases only those types of analyses can provide the necessary information for a full diagnosis. There are many evidences as the example described in on the case of a neo-gothic church in Pamel, near Brussels [4] that the analyses of the pore structure of the mortars and bricks, and the chemical composition of the different mortars used, are necessary to define whether the damage to the brick was due to the mortar or to the composition of the bricks. In this matter the project has the task of proving the interest of different types of analysis for the diagnosis of damage and to stimulate proper diagnostic methods in that respect.

Within the project the questionnaire is also used as a structured way of collecting documentation on different cases from all the partners. Examples from Belgium, Germany, Italy and the Netherlands have also been documented in this way. The full-scale masonry models of the Politecnico di Milano set up for monitoring damage processes are also included to check the possibility of evaluating the effectiveness of the questionnaire from a dynamic viewpoint, i.e., can the questionnaire inform us about the speed of the degradation process [5]?

2.4.3 Damage atlas.

A classification of damage patterns found in brick masonry has been set up [6]. The terminology used follows the same structure and setup as the questionnaire and the Masonry Damage Diagnostic System. The definitions are more extensive than the definitions presented in decision table form in the Masonry Damage Diagnostic System and possible damage causes are also given. A complete set of illustrations of the different damage types is provided in the atlas with an explanation about the possible causes of the damage. Consistency with the Masonry Damage Diagnostic System was guaranteed as they were developed to be used together. An example of a page of the damage atlas as it will be published is given in Fig. I.

2.4.4 Masonry damage diagnostic system.

The Masonry Damage diagnostic System (MDDS) [7] is a Knowledge-based System (KBS). It is a database with information and additional knowledge to create relations according to given answers and questions. It is the translation of expertise into a system computers can handle. The knowledge is structured and can be consulted using a **Decision Table** System Shell (DTSS) developed by TNO-Bouw. It is actually a programme running on Macintosh computers but a Windows version is on its way. The Masonry Damage Diagnostic System is a prototype and is not for sale. It is the aim of the partners of the project to create links with organisations that would like to develop the existing system for their use and co-finance in this way the updating and extension of the system.

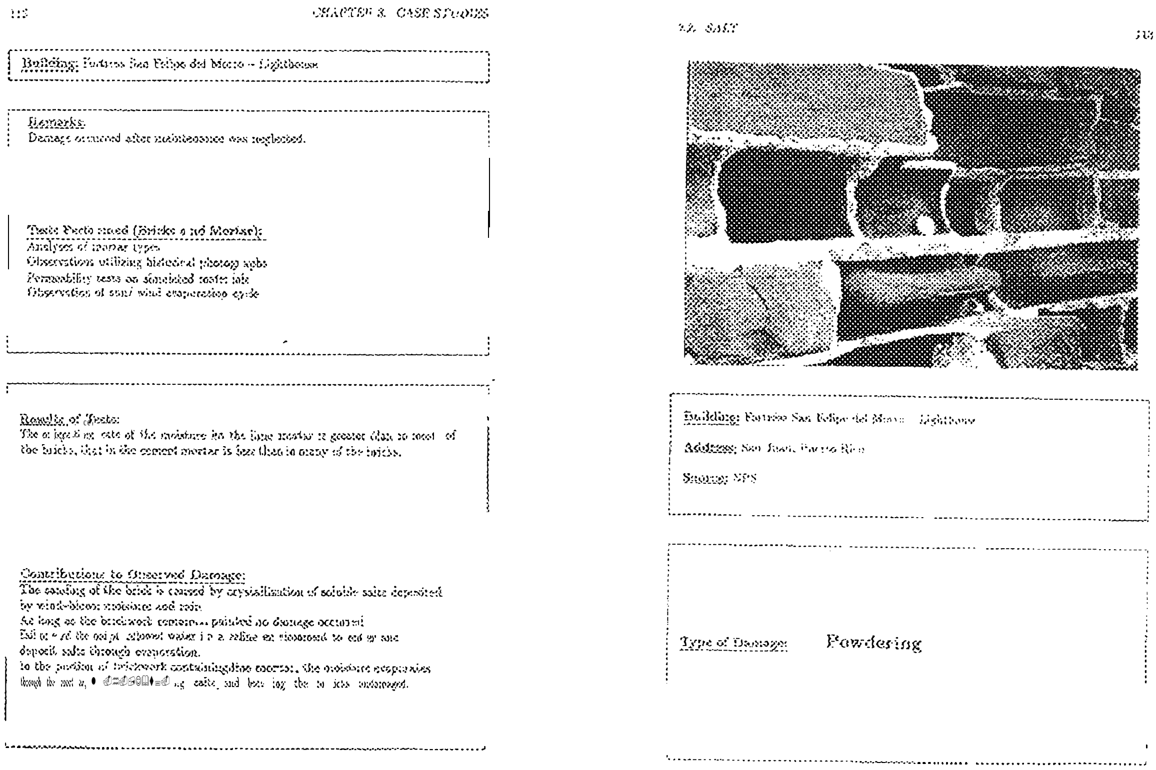

Fig. 1: : Example of a page of the damage atlas.

The knowledge is translated into a large set of decision tables themselves containing sets of conditions and actions. The set of condition tables is structured in a hierarchic way and can be presented as a decision table tree [8].

Fig.2 presents the starting branches of the tree with the sub-tree of processes checked by the system. Fig.3 shows the tree of the damage types.

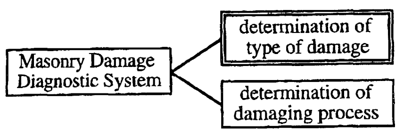

Fig. 2: : Tree structure of the main branches of the Masonry Damage Diagnostic System: determination of the type of damage (detail in next figure) and checking of damaging process responsible for the damage.

The computer programme aims to make the consultation of the Masonry Damage Diagnostic System user-friendly. In contrast to the questionnaire the Masonry Damage Diagnostic System will adapt its questioning according to previous answers given. Comparative data as pictures and comparative results of test trends are also given so that if there is uncertainty or when the answer to be given is not clear, additional information can be consulted. A typical screen picture is given in Figure 4.

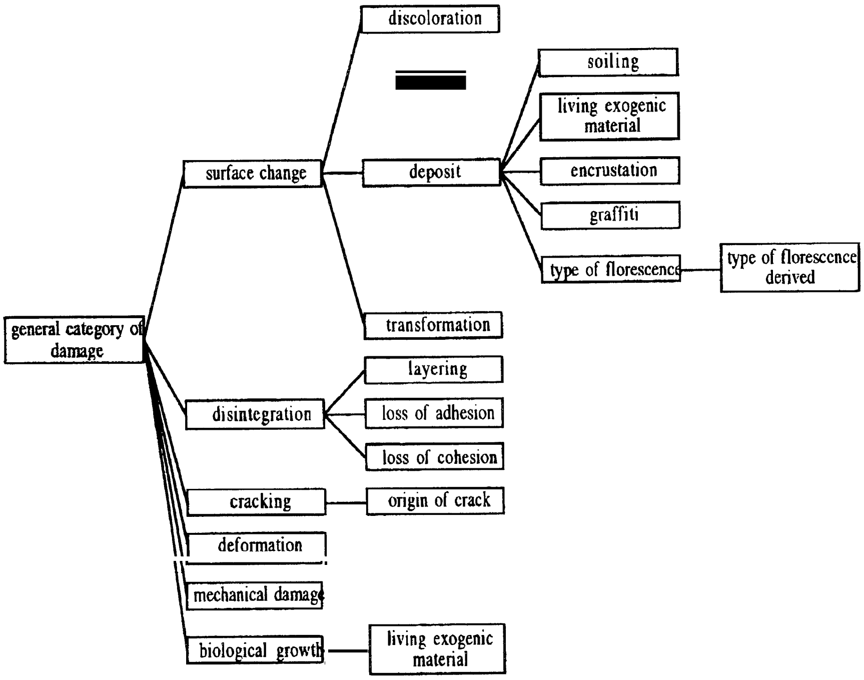

Fig. **3:** : Structure of the decision tables containing the knowledge about the determination of damage types; the hierarchic approach corresponds with the structure of the damage atlas.

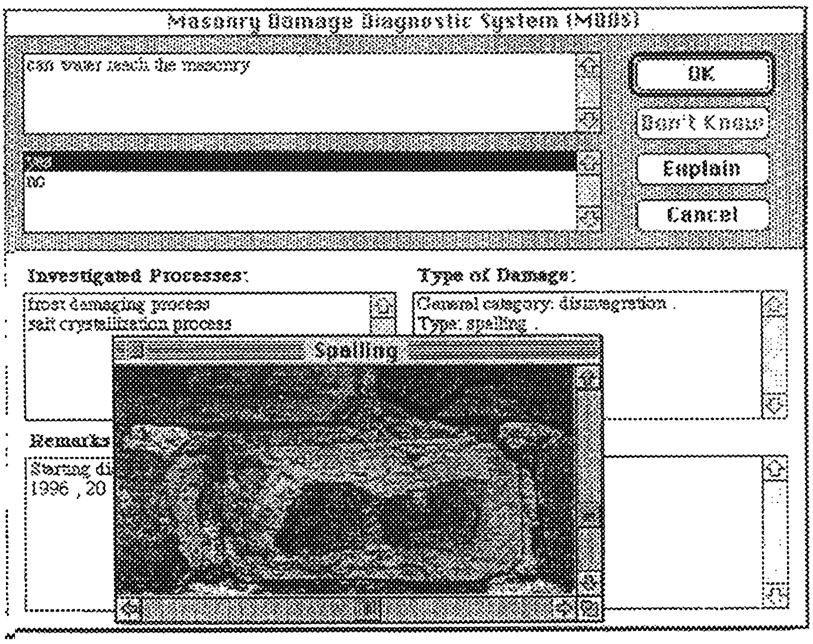

Fig. 4: : Example of a consultation screen using the Masonry Damage Diagnostic System.

The output of the Masonry Damage Diagnostic System is given immediately on the screen, but a printed report of the consultation is also generated. This document can be used as a report by the user. The results of a consultation can be stored in a file which allows progressive and step-by-step consultation in different stages. During the progress of the project it has been shown that it is very useful to create, using the Masonry Damage Diagnostic System, an interesting collection of examples of damage. The structure of the KBS within the Masonry Damage Diagnostic System obliged the users to work in a very systematic way while developing the system and using it afterwards.

3 Conclusions

The description of the damage types on historic brick structures has been improved. The link between terminology, questionnaire, damage atlas and Masonry Damage Diagnostic System is guaranteed by accurate definitions and the hierarchic concept of the damage types descriptions. In the same way the description of possible damage causes and the processes leading toward the above-mentioned damage types have been improved. The increase in systematization which was sought by the project is a necessary and interesting by-product of the creation of Knowledge Base systems (KBS).

The Decision Table System Shell (DTSS) has proved to be a very interesting tool for the development of the KBS.

The collection of different types of information using the questionnaire and other related summary sheets allowed the research team to make an interesting collection of degradations of different types. Those examples are useful for the elaboration of the damage atlas.

Reactions on the complexity of the questionnaire and uncertainty on the part of the user about which information should be mentioned in this document prove the advantage of the Masonry Damage Diagnostic System. It is certain that in the dialogue between the expert system and the user the latter will feel more comfortable as he will think that the questions which are asked are relevant to the problem, though on the other hand the expert system will limit his questioning only to that information it can consider in its reasoning. Further development of the Masonry Damage Diagnostic System could be guaranteed by the integration of research results from other projects and by the inclusion of data available on the degree and effect of pollution. Let us not forget however that no expert system will ever be as competent in each of the domains of expertise as real experts. Nevertheless the Masonry Damage Diagnostic System will be of great interest for many routine operations where leading professionals are now wasting their time and could be replaced by low-profile professionals if they are helped with a system such as the Masonry Damage Diagnostic System, provided that one issue of the system remains: “for this (difficult and complex) case I have no answer. Please call an expert”.

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References:

[1] Van Balen K., (1997) Monitoring of degradration in view of the selection of treatment strategies, in: BAER N. S., SNETHLAGE R. (Eds) *Saving Our Architectural Heritage: the conservation of historic* stone *structures,* J. Wiley and Sons Ltd., Chichester, pp.1 67-180;

[2] Van Balen, K., Mateus, J., (1993) Broad categories for causes/agents of damages, *unpublishedproject document,* K.U.Leuven, 12 p

[3] Van Balen, K., Mateus, J., (1994) What damage can we see and how?, *unpublished Project report on task 1.2.4.*, 78p.

[4] Van Gemert, D., and K. Van Balen, (1988) The influence of pointing mortar on the alteration of brick and masonry, *Proceedings of the 8th international Brick, Block Masonry Conference,* p. 175 1-1758, Elsevier Applied Science, London and New York.

[5] Binda, L., Baronio, G., (1993) Presentation of the full scale masonry models and the monitoring of damage process, Nato-CCMS Pilot study "Conservation of Historic Brick Structures" meeting, Venice 22-23/11/93.

[6] Francke, L., Schumann, I., (1993) Classification of damage patterns found in brick masonry, unpublished project report, TUHHarburg, September 1993, 43p.

[7] Van Hees, R., (1995) Entwicklung eines Systems fur die Diagnose von Schaden an historischem Ziegel-Mauerwerk auf der Grundlage eines Knowledge Based System, in E.G. Niël (Ed.), *Instandsetzen von Mauerwerk*, WTA-Schriftenreihe, Heft 6, Aedification Verlag, pp. 12- 18

[8] Van Hees, R., and Silvia Naldini, 1995b. The masonry damage diagnostic system, *International Journal for restoration of buildings and monuments,* Vol.1, No.6, pp. 46 l-474.

The performance of surface treatments for the conservation of historic brick masonry

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Abstract
An evaluation was made of the performance and the effectiveness of surface treatments, mainly water repellents, applied in the past on historic brick masonry. In the three European countries involved in the project over 60 case studies were carried out. Besides, laboratory research was carried out, so that the two research lines could be combined. The main aim of the project was the assessment of the performance of surface treatments for the conservation of masonry monuments, and, further, to evaluate the risks of failure and damage and to develop methods for the prediction of the performance.

Essential for the assessment of the performance of water repellents in the field and in the laboratory is the water repellent behaviour, checked on the brick / mortar system, and the evaluation of any damage observed, in relation with the presence of the treatment. This approach to the evaluation of the effects of treatments, using materials in combination, forming thus a system, proved to be very important: a different behaviour of brick and mortar after treatment could be observed, as well as interactions and mutual influences.

The *effectiveness* (water repellency) of a treatment can last for a long time, even more than 30 years. To this conclusion the following should be added: i) there is no clear relation between the age of the treatment and its effectiveness, ii) the effectiveness of the treatment within one building, even within one wall is quite variable, iii) the mortar joint is, from the point of view of water penetration, the weakest part of the (treated) system. The main reason for an insufficient performance of treatments lies in most cases in the lack of preliminary investigations, meant to outline the state of conservation of a building and to furnish the basis for: i) deciding on the necessity of a treatment, ii) selecting the most suitable treatment product.

This paper is an elaboration of the Summary Report, by R.P.J. van Hees and S. Naldini, which forms part of the final report on the project 'Evaluation of the performance of surface treatments for the conservation of historic brick masonry'. The project was carried out within the EU Environment Programme, under contract nr. EV5V-CT94-05 15.
Keywords: historic brick masonry, water repellents.

1. Introduction

Surface treatments, as part of the conservation, are carried out aiming to preserve from further decay and to prolong the life in service of monuments.
The application of surface treatments (of the type studied) on historic buildings started in the 1960's, but still the knowledge on treatment products and their effects on the materials should be improved. The situation in the three participating countries, Belgium, Italy and the Netherlands forms the base for this research project. The situation in the three countries is considered reasonably representative for the countries within the European Union.
In Italy treatments have been always used, whereas in Belgium they were not met with favour in the beginning; in the Netherlands only water repellents have been applied: after a period of favour, the attitude has become more cautious.
Main aim of the project was, to improve the knowledge on the effects of surface treatments on the service life of walls in historic buildings; most important aspects are: i) the performance in the course of time, ii) the risks of failure and damage, iii) the prediction of the performance.
In this paper an overview is given of the main research lines and results of the project, without however being extensive and complete.

2. Methodology

2.1 Research lines

The evaluation of the performance and durability of surface treatments resulted the following (interrelated) research lines:

- assessment of the state of preservation of treated walls of historic buildings;
- assessment of the performance of treatments in laboratory, making use of: i) single materials, ii) little test walls (combination of materials, that is brick and mortar), iii) real scale test buildings located in the open air.

In Italy and Belgium, water repellents (protectives) are often used in combination with consolidants, whereas, in the Netherlands, only water repellents are used. The study of water repellents was therefore essential to evaluate the state of treated monuments.
Treated monuments to be investigated were chosen with the help of the authorities in charge of their care, restoration architects and producers of treatments. Prior to the investigation on treated walls in monuments, a research was carried out aiming at collecting information on the reasons for treating, the treatment performed and the methodology followed. The results of the research where quite alarming:

- in most cases no report existed on the work performed;
- information was difficult to be obtained;
- motivations for treating, when traceable, were hardly scientifically based.

Therefore it is advised that authorities should dispose of reports on treatments performed (incl. motivations and monitoring), which should be available for consultation.

A study was carried out on the attitude of governmental Bodies responsible for the monuments towards treatments. The restoration ethics of each country influences the philosophy of the conservation interventions. Although in several countries guidelines on treatments exist, there may be a gap between theory and practice.

2.2 The choice of materials and of treatment products for testing

Old, traditional and (to a certain extent) inhomogeneous bricks were used for testing, as they possess similar characteristics to those of the bricks found in monuments. Further, the choice was based on the fact that they also have a life in service and a history. Mortars were chosen that are used for restoration in the participating countries.

Water repellents and consolidants were chosen, which were and still are available on the market; the selection was completed with a water repellent which had been used in the past, but was no longer available. The products were obtained from the producers. 4 Types of water repellents (8 on single materials) and 2 types of consolidants have been used in the laboratory research.

3. Results and discussion

3.1 General

In the study on the attitude of authorities towards treatments it was found that:

- Documents concerning philosophical and ethical aspects of restoration are often found too theoretical and far from the practical problems met by those involved in conservation.
- Guidelines on treatments are sometimes so extensive and therefore so complicated that they are not used. End users need above all realistic guidelines and documents.

Important conclusions on the performance of treatments could be derived from the combination of results obtained in laboratory with results obtained in case studies.
The water repellent effect of a treatment can not be considered the only criterion to assess its *performance.* The performance of a treatment should be evaluated, taking into account its various functions, which are or are claimed to be:

- to make the treated surface water repellent and to avoid water penetration;
- to protect the surface from damaging mechanisms in which moisture is essential;
- to avoid chemical transformation of calcitic materials, due to wet and dry deposition and moisture;
- to prevent biological growth (especially thriving of algae).

Essential for the assessment of the performance of water repellents in the field and in the laboratory is the water repellent behaviour, checked on treated brick, mortar and the *brick / mortar system,* and the evaluation of any damage observed, in relation with the presence of the treatment. This approach to the evaluation of the effects of treatments, using materials in combination, forming thus a *system,* proved to be very important: a different behaviour of brick and mortar after treatment could be observed, as well as interactions and mutual influences.

3.2 Laboratory research on single materials, little walls and test buildings

3.2.1 Single materials

Research on single materials has confirmed [4] that for one type of substrate, differences in effectiveness are obtained after ageing, even within one class of chemically similar water repellents. Moreover, for one type of water repellent, the effectiveness depends on the substrate.

3.2.2 Little walls

The research showed that both water repellents and consolidants do improve the durability of mortar joints under the attack of acid rain. Water repellents, though, provide the better protection. Treatments (both water repellents and consolidants) may give a (short term) protection against the growth of algae.

A big difference was found in laboratory comparing the consumption of treatment products applied by capillary absorption (as is usual in case of small specimens of single materials) with that of products applied by spraying until they flow over the surface (as done in case of wallettes). Also a big difference in penetration depth was found, especially concerning mortar joints. These findings are important as they underline the difference that might exist between results of tests in laboratory and the performance in practice.

3.2.3 Test buildings

The research on the walls of test buildings meant for studying the effects of treatments confirmed the above mentioned results showing that:

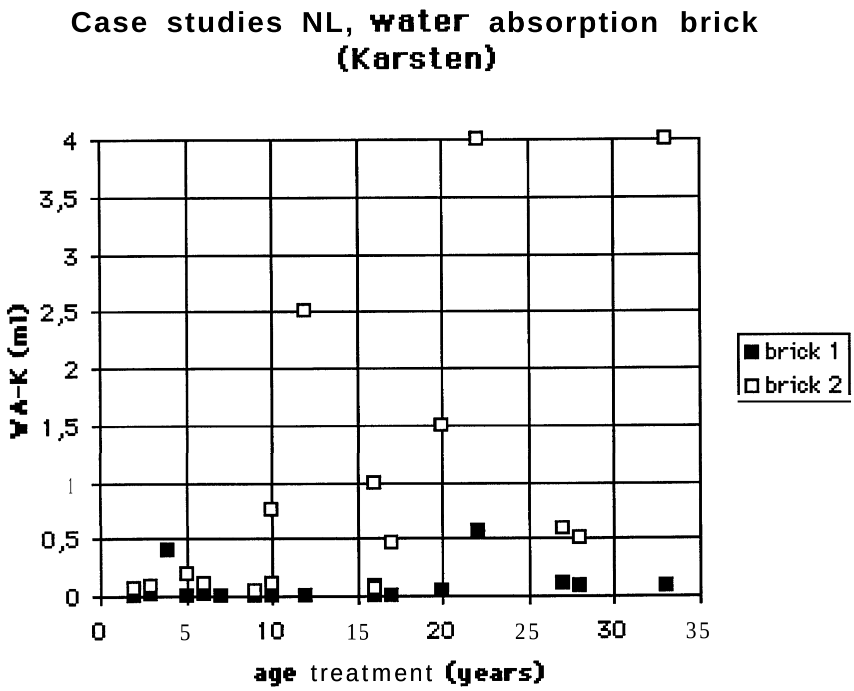
- the way of application of treatment products can affect their penetration depth;
- decay related to rain penetration can take place when pointing is not treated:
- in the case of repointing, the new material should also be treated;
- the damaged (pointing) mortar should be maintained (repaired, substituted) before treatment, in order to avoid the occurrence of damage.

3.4 Performance and failure. Combination of field and laboratory research

The *effectiveness* (water repellency) of a treatment can last for a long time, even more than 30 years (see fig. 1). To this conclusion the following should be added:

- there is no clear relation between the age of the treatment and its effectiveness;
- the effectiveness of the treatment within one building, even within one wall is quite variable;
- the mortar joint is, from the point of view of water penetration, the weakest part of the (treated) system.

Although treatments have in general only a limited influence on vapour diffusion, their influence on the drying behaviour of masonry is considerable. The drying behaviour of treated masonry was investigated in this research project as one of the aspects of the performance of the treatment. The impact of treatments on drying proves to be quite high. The importance is mainly shown in cases of water penetration (incl. rising damp, leakages..) where the slower drying behaviour may support the development of damage.



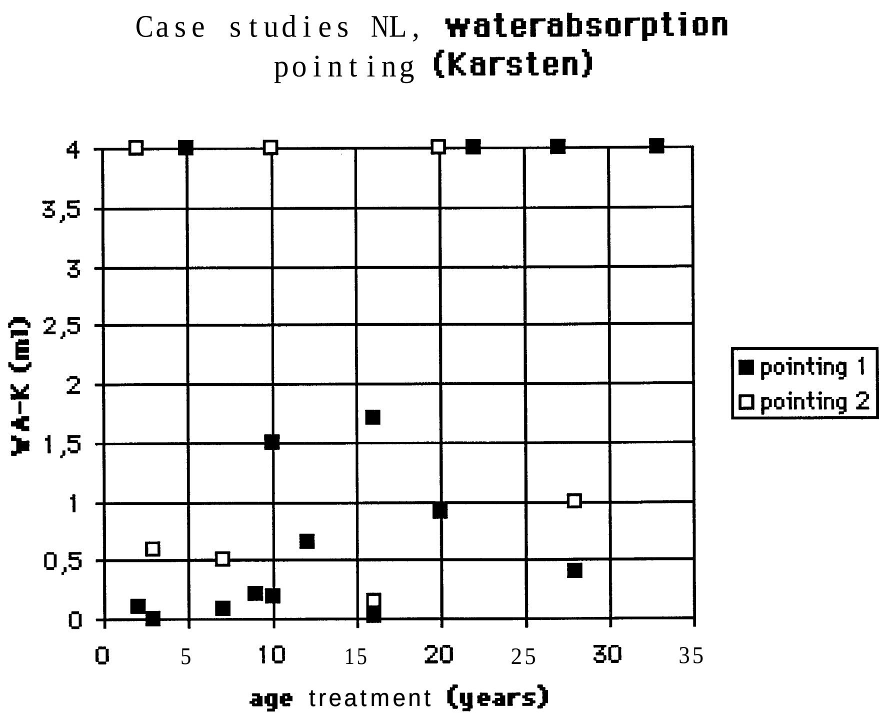


Fig. 1 Effectiveness of water repellents. Water absorption (Karsten pipe) on brick and pointing; best and poorest values for case-studies in the Netherlands, WA-K (ml)= abs. after 15 min. -/- abs. after 5 min., see [l].

Re-treatment of substrates (treated with a water repellent in the past) is possible. The first treatment has the highest influence on the drying behaviour. Only in case of the first treatment being a water based product, the next treatment was found to have a significant influence on the drying behaviour.

Failures and causes of failure were evaluated. Combining the results of the research in the field with those of the research in laboratory, the main causes of damage could be understood and the role of the treatment evaluated, see [2], [6]. Important results are:

- treatments play an important role in damaging processes such as salt crystallization and frost action: they may increase the damage to the materials or contribute to develop circumstances suitable for damaging processes to occur;
- treatments can not (always) offer protection against dry deposition attack: (black) crusts (gypsum) were found both in treated monuments and obtained in ageing tests on treated materials;
- the application method has an important influence on the effectiveness of the treatment: a different effectiveness was observed comparing brick and mortar joints; a low effectiveness of a treatment on mortar may explain water penetration through mortar joints of a treated wall;
- lack of scientifically based planning and lack of knowledge on the behaviour of treatments have serious consequences on the effects of treatments: in the case of repointing of a treated building, for example, if new pointing is not treated, the possibility of water penetration is almost equal to masonry not treated at all, which increases the risk of damage;
- the lack of knowledge on products available on the market is quite alarming. Products, of which the actual composition is not indicated, are put on the market as *reversible, natural, offering protection* to the materials, without affecting them, which responds to marketing strategies more then to the needs of the conservation of monuments. A method was developed to determine the type and origin of a product, applied in the past. This method allows to make a ‘fingerprint’ of the applied product which can be compared to that of known products.

4. Conclusions and recommendations

The knowledge on historical building materials and on conservation treatments possessed by the people involved in conservation, at all levels, needs improvement: local authorities and restoration architects and technicians (the responsible people in restoration campaigns) should be provided with thorough, but essential and clear guidelines on treatments (when, how to perform treatments). An important task for scientists is to make the results of their research available and applicable in practical situations for different groups of end users.

The main reason for an insufficient performance of treatments lies in most cases in the lack of preliminary investigations, meant to outline the state of conservation of a building and to furnish the basis for:

- deciding on the necessity of a treatment;
- selecting the most suitable treatment product.

'Golden rules' are proposed including the methodology to carry out an effective preliminary research, as well as guidelines to evaluate the obtained results in view of a treatment, and the clue to select the correct treatment product (when necessary).
The main points for correctly proceeding in treating monuments are summarised as follows:

- Pre-investigations should be carried out for evaluating the state of preservation of the monument, before deciding to use a treatment. The research should be centered on the definition of the type/s of decay present and on the diagnosis of the decay mechanisms leading to it/them (in particular: presence/sources of moisture, salts; ref. [3], [6]).
- In order to avoid confusion clear terminology and definitions to indicate damage should be used. Definitions should be preferably based upon existing sources like MDDS or Damage Atlas, that were developed in the EC project Expert system for the evaluation of the deterioration of ancient brick masonry structures (EV5V-CT92-0108), see [5], [7].
- A well balanced choice should be made on treating or not treating and eventually on the type of treatment. The decision should be based upon the results of the pre-investigation.
- Before treating, repair and substitution work (e.g. detailing, pointing, cracks; incl. leakages and rising damp) should be done, for a good performance of the treatment.
- The quality of products to be used should be guaranteed (for example through certification).
- The applicator should take into account the difference between brick and mortar and the possible consequences of the inhomogeneity of the materials.
- Restoration archives should be kept and maintained by the authorities. Archives should be accessible for all people dealing with the conservation of monuments.' Treatment should be considered an important intervention and therefore be documented in the restoration archive.
- Control (monitoring) and maintenance of treated masonry are necessary. In case of interventions like repointing, re-treatment needs to be done.

Future research
Several items were met that could not be studied in depth during the current project. The most important findings that need further investigation and meet a real need in building practice are given here:

- Algae growth, a problem that occurs even after treating masonry with a water repellent.
- Problems concerning mortar joints (loss of bond, pushing out, disintegration) are considered to be among the most budget consuming maintenance questions. Maintenance, repair and choice of material are a very important research item.
- Limits (quantity and quality) of salt content in relation to treatments.

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References

1. Hees, R.P. J. van, Klugt, L. J.A.R van der, De Witte, E., De Clerq, H., Binda, L. And Baronio, G. (1995), *Test methods for the evaluation of the in situ performance of water repellent treatments,* Proceedings of the First International Symposium on Surface Treatment of Building Materials with water repellent Agents, Delft.
2. Klugt, L.J.A.R van der And Koek, J.A.G. (1995), *The effective use of water repellents,* Proceedings of the First International Symposium on Surface Treatment of Building Materials with water repellent Agents, Delft.
3. Binda, L., T. Squarcina, T. And Hees, R.P.J. van (1996), *Determination of moisture content in masonry materials: calibration of some direct methods,* Proceedings 8th International Congress on Deterioration and Conservation of Stone, Berlin, pp. 423-435.
4. De Witte, E., De Clercq, H., De Bruyn, R. And Pien, A. (1996), *Systematic testing of water repellent agents,* International Journal for Restoration of Buildings and Monuments, Vol. 2, no. 2, pp. 133-144.
5. Van Balen, K., Binda, L., Hees, R.P. J. van And L. Franke, L. (1996), *Damage to historic brick masonry structures,* Proceedings 8th International Congress on Deterioration and Conservation of Stone, Berlin, pp. 1687-l 693.
6. Hees, R.P.J. van, Koek, J.A.G., De Clerq, H., De Witte, E., Binda, L., Ferrieri, E.D. And Carraro, E. (1997), *The assessment of the performance of surface treatments in the field. Results of 60 case studies confronted with lab results,* Proceedings 4th International Symposium on the Conservation of Monuments in the Mediterranean Basin, Rhodes, pp. 395-413.
7. Hees, R.P.J. van And Naldini, S. (1997), *Diagnosis and damage to historic brick masonry. Development and use of a knowledge based system,* submitted for publication in: WTA Schriftenreihe Instandsetzen von Mauerwerk

Non-destructive tests and computer methods applied to the conservation of historical buildings

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Abstract
The problem of maintenance and recovery of historical buildings is addressed, by focusing on diagnostic methods and final check of restoring techniques. Basic issues and results are discussed, which are concerned with a research project supported by the *European Commission - Environment and Climate Programme* (Contract EV5V-CT92-0106). The project was centred upon the application of non destructive test methods, numerical models for structural analysis and parameter estimation techniques to be applied before and after the use of reinforcement techniques. A major objective of the work program was the definition of criteria and guidelines for an optimal choice of the most convenient experimental methods. To this aim, applications to real, practical cases (before and after treatment) were considered. Some emphasis was given to the Ground Probing Radar (GPR), to sonic measurements and to a new approach based on electromagnetic monofrequency waves (a technique that allows one to measure water content and to obtain tomographies suitable for checking grouting processes).

The problem of structural assessment was also discussed by considering system identification approaches, which are suitable for estimating material constants and for detecting damage processes. Further efforts in the context of computer methods were made to study and develop convenient numerical models for masonry.

Next, pseudodynamic tests on shear brick masonry walls were considered with the aim of studying the behaviour of injected materials and/or reinforcement techniques in the presence of time-dependent loads. Thus, a simple pseudodynamic testing procedure was developed and evaluated as a possible experimental method suitable for obtaining useful information on materials and on techniques aimed at monument rehabilitation, without any destructive or intrusive action upon the building.

Eventually, the following goals of the research programme were achieved:

- calibration of sonic techniques and GPR for monuments made of brick and stone masonry, with particular emphasis given to the evaluation of grouting processes
- use of monofrequency electromagnetic waves to detect moisture content and/or perform 2D- and 3D-tomography for the evaluation of grouting processes
- better knowledge of classical techniques and enhanced capability of combining different experimental methods in order to optimise their use
- development of a pseudo-dynamic testing procedure to evaluate injections and, in general, reinforcement techniques in the presence of time-dependent loads

Keywords: Cultural heritage, diagnostics, monitoring, non-destructive tests, numerical models, pseudodynamic tests, system identification.

1 Introduction

Non-destructive investigation techniques [1-5] are largely used because of the outstanding advantages they provide in many different fields, from quality check of industrial processes to medical applications, from monitoring of structures to the control of environmental actions. In recent years a constant effort was made in order to exploit non-destructive tests for the conservation of monuments. In this area, they offer enormous benefits, since the structural behaviour can be continually monitored, the effects of environmental factors can be checked, the basic features of hidden parts can be explored and, to some extent, the mechanical properties of materials can be determined. Test data also represent an important support for numerical approaches applied to historical buildings, since they give information on the accuracy of numerical results (in terms of displacements, strains, vibration frequencies and so on). Experimental methods may also be combined with system identification procedures [6-12] and provide optimal values of unknown parameters.

The consciousness of the above issues and the wide-spread interest in non-destructive testing techniques are also reflected by an impressive effort made by the European Commission in order to encourage research projects largely focused on the use of non-destructive experimental methods [13]. One of these projects, coordinated by the author, was explicitly devoted to non-destructive tests, numerical models for structural analysis and parameter estimation algorithms to be applied before and after the use of reinforcement techniques. A comparative study of non-destructive investigations was performed with the aim of establishing criteria and guidelines for an optimal choice of experimental methods applicable to the conservation of our architectural heritage. The work program was largely based on practical cases and several *in situ* tests were performed in France and in Italy, by utilising electromagnetic methods, sonic measurements and flat jacks (devices that give useful information on elastic constants and local stresses in masonry structures). New experimental techniques that make use of electromagnetic monofrequency waves were also studied and developed, with the aim of measuring water content and obtaining two- or three-dimensional tomographies, which allow for a critical evaluation of grouting processes [5,14].

The project was also centred on numerical models for brick masonry (accounting for damage and plastic strains), on system identification approaches and on a simple pseudodynamic testing procedure, applicable to masonry shear walls and suitable for checking injections and/or reinforcement methods subject to time-dependent loads [15].

2 Seismic methods

Most of the experimental activity was concerned with sonic measurements and electromagnetic techniques. These methods are derived from geophysics and, in general, provide information about the space distribution of a physical quantity (sonic velocity, dielectric permittivitty and so on). Unfortunately, a direct relation with mechanical properties can hardly be found, in spite of some successful applications of sonic tests that provide some correlation between sonic velocities and stiffness parameters. In any case, geophysical observations clearly describe the general features of the observed objects at a cheap price and without any damage, suggesting optimal locations for further, partially intrusive investigations (such as endoscopy and mechanical tests on cores). As obvious, the performance of each method highly depends upon the specific application and is controlled by several parameters. Thus, a major goal of the research project discussed here was to compare different techniques when applied to different practical situations encountered with historical buildings.

In the case of sonic tests travel times of seismic waves across a medium are measured. Measurements of this kind straightforwardly provide average velocities of the seismic waves, because the distances between transmitting and receiving devices are known. In this way a sort of average information is obtained, that depends upon physical properties of the media encountered by the wave along its path. Therefore, when average seismic velocities are mapped, inclusions or areas characterised by damaged materials can be detected. It is possible to enhance the method by means of two- or three-dimension tomography [16-18]. In this case, the information given by several measures of travel times provides a detailed map of velocities inside the wall. Essentially, hundreds of rays (paths followed by the seismic waves) are determined by using several receivers for each source. Next, velocity distributions are estimated by means of convenient algorithms. Typical output maps are obtained by using different colours (or different shades of grey) and by relating colours to velocities. A significant application is shown in Figure 1, where sonic velocities (as measured before and after injections) are reported with different colours. Measurements were taken at a pillar of the bell-tower of Chioggia Cathedral (near Venice, Italy). Data reported in Figure 1 refer to a cross section of the pillar. The effect of injections can be clearly noted as white areas correspond to higher velocities, which denote a decrease of voids.

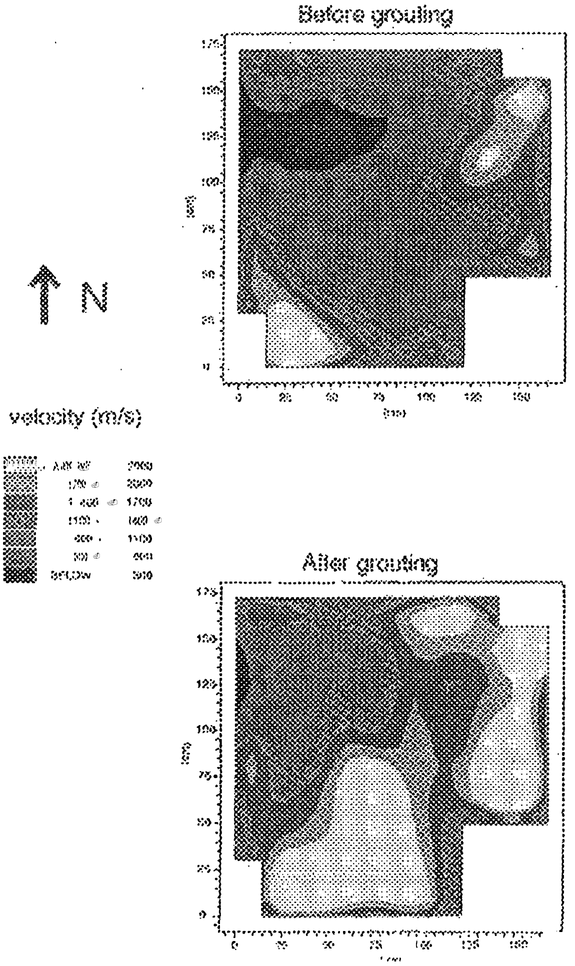

Fig. 1 - Sonic tests performed by LCPC, Centre de Nantes, before and after grouting [5]

3 Electromagnetic methods

Electromagnetic waves can also be considered for investigating hidden areas, since their propagation inside a medium also depends upon physical properties. Experimental tests on monuments are usually performed by using frequencies in the range between some hundreds MHz to 1 GHz. Waves are generated by means of specific antennas. When the so called reflection mode is used, the same device acts both as transmitter and as receiver, while the so called transmission mode requires a second antenna (receiver).

Probably, the most popular device that makes use of elecromagnetic waves is the Ground Probing Radar (GPR), originally developed for geophysical applications. It can be used in the transmission mode. The measured quantities are the velocities of short electromagnetic pulses, whose travel times depend upon electromagnetic properties of the medium (such as permittivity or conductivity). It can be applied to homogeneous structures and provides information about the presence of inclusions and/or different materials. Since large areas can be explored in relatively short times, it is an excellent non-destructive technique suitable for detecting potentially critical locations, where further investigations (e.g., sonic measurements) or samples for mechanical tests may be needed. Depth penetration is about 1 m with brick masonry and a few metres with stone structures. The GPR method can also be used in the reflection mode. In this case, pulse echoes reflected on heterogeneities are detected. The technique is useful to find fractures and inclusions. It is usually effective if the depth is less than 1 m with brick masonry, while a few metres are possible in the case of stone structures. Results are mostly presented by using profiles in pseudocolours (with different colours corresponding to different electromagnetic velocities). An application is shown in Figure 2, concerned with a stone wall at the Castle of Vincennes (Paris). The length of each thin (essentially vertical) line is proportional to the travel time needed to cross the medium and come back. The straight, thick line at the top corresponds to the surface along which the antenna is moved, while the thick lines underneath correspond to the end of the wall. Travel times are similar and show a homogeneous zone.

One further, possible application of electromagnetic waves in the so called transmission mode consists of using monochromatic (monofrequency) waves rather than pulses In this case, the measured quantity is their attenuation. The technique is applicable to homogeneous structures and allows one to detect moisture [5], to evaluate the global homogeneity of a medium and to define convenient locations for drilling cores. During the development of the project, monofrequency waves were used in Venice (Scuola Grande di S. Rocco) in the presence of high levels of moisture, since a wall facing a canal was tested. Measurements showed an excellent correlation between higher attenuation and higher levels of humidity at locations close to the canal. Another set of tests was carried out in the framework of the project at Padua (bell-tower of Santa Giustina's Church), where monofrequency waves were used before and after injections. Next, tomographies were obtained (cross sections fully analogous to the ones shown in Figure 1). Also in this case the performance of the method appeared quite good, since a lower attenuation (and, hence, a reduced presence of voids) was found after grouting.

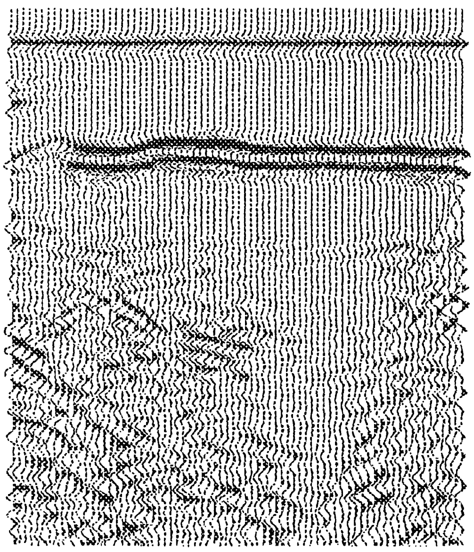

Fig. 2 - GPR tests performed by LCPC, Centre de Nantes [5]

4 System identification

System identification plays a major role in the conservation of historical monuments, since it provides optimal values of unknown parameters that characterise a system. Such parameters may be concerned with the global response of a structure (such as elastic constants and/or damping factors), with local effects (such as damage phenomena) or with the nonlinear behaviour of materials (such as yield limits and/or hardening moduli). Optimal values of unknown parameters are found by minimising the difference between the response of a structure to a given input and the response (to the same input) computed on the basis of a discrete model. Thus, the solution of the problem requires a close interaction between numerical modelling and non destructive tests. Both deterministic and statistical approaches can be followed. The second approach takes into account error measurements, uncertainty concerned with initial parameter estimates (as suggested by previous experience) and uncertainty concerned with final parameter estimates (after applying the parameter estimation procedure).

Two problems were considered during the development of the project and were solved by using a Bayesian approach, so that error measurements and *a priori* knowledge were accounted for. The first problem was concerned with material characterisation and Young's moduli were estimated. An iterative procedure [19] was needed, since the problem is nonlinear. The approach was explored by testing a brick masonry shear wall. First, some severe damage was induced by means of cyclic loads. Next, the wall was reinforced by injections. Parameters were estimated before and after injections. Numerical results were supported by the outcome of sonic measurements, that showed a satisfactory agreement between higher stiffness parameters and higher sonic velocities. The second problem concerned with system identification was centred once again on the estimate of stiffness parameters, but vibration frequencies were assumed as measured data. Also in this case a Bayesian approach was followed [20] and parameters were estimated for the bell-tower of Chioggia Cathedral.

5 Pseudo-dynamic tests on masonry shear panels

The project presented in the paper was also concerned with pseudodynamic tests on masonry shear walls. Thus, a test procedure was investigated, which is suitable for inducing damage by using a standard load history (a sort of pseudo-random sequence of external actions). In this way different structural components may be subjected to repeatable time-dependent loads and their behaviour can be studied in an objective way before and after injections or reinforcements. In our case loads were applied by using the El Centro record (1940) and by imposing different values to the peak ground acceleration, say a_{max}. Both unreinforced and reinforced walls were tested by using a simple steel frame suitable for applying compression and shear loads to mason& walls by means of two vertical screw jacks and one horizontal screw jack (*cf.* Figure 3).

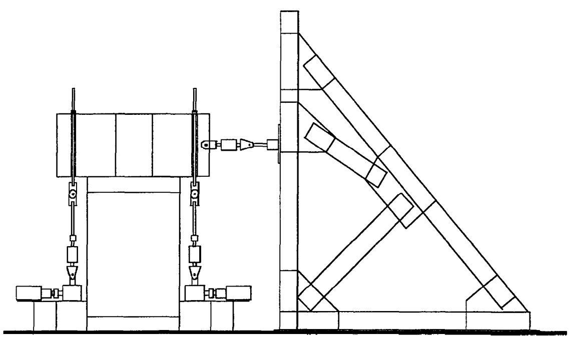

Fig. 3 - Test rig (University of Trieste)

As typical with this kind of tests, experimental and numerical methods were combined. Indeed, by considering a certain ground acceleration record and by assuming one mass located along the upper edge of the wall, the classical equation of motion for one-degree-of-freedom systems was solved: $m\,a + c\,v + r = f$. Here, m is the mass, c the damping parameter (to be properly selected), a the acceleration, v the velocity andf the applied horizontal force. The parameter r represents the force that would occur if a given displacement were imposed in a quasistatic way. Note that r depends upon the current stiffness of the system and is often unknown in many practical cases concerned with damage processes. For the numerical solution of the governing equation, the time history was divided into a convenient number of steps and, at each step, displacement increments were found by using an explicit algorithm (that is, on the basis of the values attained by acceleration, velocity and displacement at the beginning of the current step). Of course, at the beginning of the first time interval both the displacement and the velocity are zero, while the acceleration a is equal to the ground acceleration. In any case, when the displacement at the end of a given time step has been computed, it is imposed to the specimen under test and the reaction r is measured by using a load cell. Next, by introducing the input force f=$m\,a_G$ (where a_G is the ground acceleration at the end of the current step), the velocity and the acceleration at the end of the time interval can be found.

Here, some results are reported that clearly show some damage induced by the testing procedure and the effectiveness of injections utilised for the deteriorated specimen. Figure 4 gives displacement vs. time plots related to five pseudodynamic tests (a_{max}=0.8 g). The plots show a significant decrease of stiffness at the end of the test sequence. Figure 5 gives similar plots for the same wall after injections. It is quite clear that no significant damage is caused by the sequence of tests and that the reinforced wall features a much better behaviour.

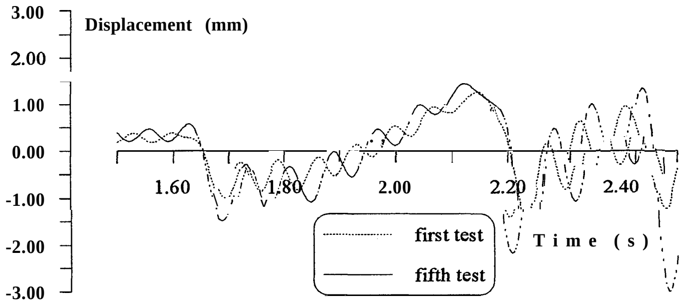

Fig. 4 -Displacement vs. time plot concerned with pseudodynamic tests

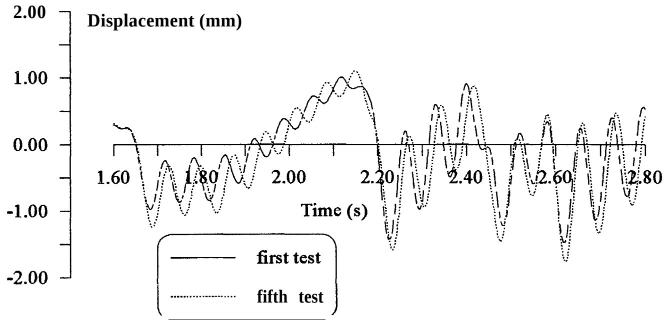

Fig. 5 -Displacement vs. time plot concerned with pseudodynamic tests (reinforced wall)

6 Closing remarks

The project presented in the paper (and supported by the *European Commission - Environment and Climate Programme)* gave the opportunity of investigating several non-destructi.ve techniques suitable for historical monuments. Classical and innovative applications could be explored, with particular emphasis given to the potential advantages provided by the combined use of different test methods. Significant applications were considered including monitoring procedures, evaluation of reinforcement techniques and diagnostics. A key feature of the project (and a major issue of the guidelines suggested by the project itself) is the interaction among different experts, such as geophysicists, architects and structural engineers.

Some emphasis was given to the application of seismic and electromagnetic methods to masonry, which is a complex material (owing to anisotropy) and is often present in historical buildings. Further interest is given by a case study concerned with a monument located in Venice, where unique environmental conditions provide a significant benchmark both for traditional techniques and for innovative methods (such as the one based on monochromatic electromagnetic waves).

Non destructive inspections based on electromagnetic waves and sonic measurements had a major role during the development of the project because of the high current interest and because of the need of investigating new potential applications. It is clear, however, that further, well established techniques (such as endoscopy, thermography and so on) may also be used when they appear to be useful and/or when their application is suggested by seismic or electromagnetic methods. Indeed, these non-destructive methods may also call for partially intrusive investigations (such as mechanical tests on cores) and/or system identification procedures (aimed at material characterisation and/or damage detection and/on monitoring).

A major problem raised by monuments is concerned with the implementation and enhancement of numerical models for structural analysis. For the sake of brevity this issue is not discussed here, but some emphasis was given throughout the project. In addition, the importance of strong interactions with non-destructive inspections was stressed, since efficient discretisations require accurate information on materials and properly selected experimental data for a reliable check of numerical results.

Finally, a simple pseudodynamic testing procedure was developed, since it may be convenient for some special purposes, such as a careful check of injections and reinforcement techniques in the presence of time-dependent loads.

7 Acknowledgements

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8 References

1. Burke, J. J. and Weiss, V., Editors **(1979)** *Nondestructive Evaluation of Materials,* Plenum, New York.

2. Bøving, K. G., Editor **(1989)** *NDE Handbook,* Butterworths, London.
3. Davies, J.L. and Annan, A.P. (1989) Ground penetrating radar for high resolution mapping of soil and rock stratigraphy, *Geophys. Prosp.*, Vol. 37, pp. 53 l-55 1.
4. Suprenant, B.A., Noland, J.L. and Schuller, MP., Editors (1992) *Nondestructive Evaluation of Civil Structures and Materials,* University of Colorado, Boulder.
5. Nappi, A. and Côte, Ph. (1997) Non-destructive test methods applicable to historic stone structures, in: *Saving Our Architectural Heritage - Dahlem Workshop Report* (edited by N.S. Baer and R. Snethlage), John Wiley & Sons, Chichester, pp. 151-166
6. Pilkey, W.D. and Cohen, R., Editors **(1972)** *System identification of vibrating structures,* The American Society of Mechanical Engineers, New York.
7. P. Eykhoff **(1974)** *System identification: parameter and state estimation,* Wiley, New York.
8. Goodwin, G.C. and Payne, R.T. **(1977)** *Dynamic system identification, experiment design and data analysis,* Academic Press, New York.
9. Natke, H.G., Editor **(1988)** *Application of system identification in engineering,* Springer-Verlag, Wien.
10 Natke, H.G. and Yao, J.T.P., Editors **(1988)** *Structural safety evaluation based on system identification approaches,* Braunschweig, 1988.
11. Carlomagno, G.M. and Brebbia, C.A., Editors **(1989)** *Computer and experiments in stress analysis,* Springer-Verlag, Berlin.
12. Donea, J. and Jones, P.M., Editors (1991) *Experimental and numerical methods in earthquake engineering,* ECSC, Brussels.
13. Fitz, S., Editor **(1993)** *European Cultural Heritage Newsletter on Reserch - Special Issue,* Vol. 7, The European Commission - DG XII, Brussels.
14. Lecocq, Ph. **(1988)** *Tomographie electromagnetique en onde monochromatique: application a la detection de cavités souterraines,* Ph.D. Thesis, Univ. of Lille.
15. Nappi, A., G. Facchin and C. Marcuzzi (1996) Structural dynamics: convergence properties in the presence of damage and applications to masonry structures, *Structural Engineering and Mechanics*, Vol. 5, No. 5, pp. 587-598.
16. Côte, Ph. (1988) *Tomographies sismiques en genie civil,* These Doct. Etat, Univ. of Grenoble.
17. Montoto, M., Valdeon, L., Côte, Ph., Calleja, L., Corral,N., Lopez, T., Sanchez, B. and Esbert, R.M. (1994) Non destructive characterization of the state of deterioration of megaliths by ultrasonic tomography: a petrophysical interpretation, *Proc. Third Int. Symp. on the Conseravation of Monuments in the Mediterranean Basin,* Venice, Italy, pp. 3-9.
18. Abraham, O., Derobert, X., Alexandre, J. and Côte, Ph. (1996) Seismic and electromagnetic tomography applied to historical buildings: a case history, *Proc. Second Meeting EEGS Europen Section,* Nantes, France, pp. 23 2-23 5.
19. Cividini, A., Maier, G. and Nappi, A. (1983) Parameter estimation of a static geotechnical model using a Bayes' approach, *Int. J. Rock Mech. Min. Sci. and Geomech. Abstr.*, Vol. 20, No. 5, pp. 215-226.
20. Collins, J.D., Hart, G.C., Hasselman, T.K. and Kennedy, B. (1974) Statistical identification of structures, *AAIA Journal,* Vol. 12, No. 2, pp. 185-190.

Durability of cracked fibre reinforced concrete exposed to freeze-thaw and deicing salt

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Abstract
The research project “Design Methods for Fibre Reinforced Concrete” is currently carried out in Denmark. The project involves studies of properties of fibre reinforced concrete (FRC) in fresh state and during hardening, calculations of FRC-structures, test methods and design tools for FRC-structures and finally durability of FRC-structures.

Durability studies are carried out by subjecting FRC-beams to combined mechanical and environmental load (chloride penetration, water uptake). Mechanical load is obtained by subjecting beams to 4-point bending until a predefined crack width is reached. A test arrangement is developed. The surface crack pattern is characterized using video-scanning and digital image analysis. Additional durability tests (freeze-thaw, water vapour diffusion, chloride permeability) and studies of pore structure are made on specimens drilled or sawed from FRC-beams after being mechanically loaded. It is the aim to identify important mechanisms for the effect of the fibres on the durability and the pore structure based on these studies.

The test programme involves three different concrete qualities, water-powder ratios of 0.5, 0.44 and 0.38 including both fly ash and silica fume. Both steel fibres (ZP, 0.4 vol%) and polypropylene fibres (PP, 1 vol%) are used as well as main reinforcement. Uncracked FRC-beams and beams without fibres are used as reference.

This paper presents results from exposure to combined freeze-thaw and deicing salt attack on concrete with water-powder ratio 0.38. The test emphasizes the need for a critical evaluation of the mix design and mixing methods when designing FRC-structures. The scaling is increased by a factor 5 to 10 when adding fibres to the concrete while the air content is below 4% by volume. The variation of the scaling increases when adding fibres. The larger the crack width of a mechanically induced crack the less scaling at freezing.

Capillary water uptake in uncracked specimens of FRC was 20-30% higher at 1°C than at 20°C for both ZP- and PP-fibres, while the temperature had no effect on the water uptake in plain concrete. Studies of the pore structure must be made to clarify the relation between scaling at freezing, water uptake and fibres.
Keywords: Air entrainment, capillary water uptake, cracks, deicing salt, degradation mechanisms, durability, fibre reinforced concrete, frost resistance.

1 Introduction

The ability of fibres to arrest cracks and to minimize the extent of cracking and the crack width is the main item for the research project "Design Methods for Fibre Reinforced Concrete". The change of crack pattern is expected to improve the durability of FRC-structures compared with plain concrete. The background for this part of the project studying the durability of FRC-structures is described in [1].

In the laboratory the different degradation mechanisms are normally treated separately and in most cases no mechanical load is involved when materials are tested for durability. However, natural exposure of concrete structures consists of a combination of mechanical and environmental load (frost, chloride etc.). Therefore, in this project specimens are subjected to combined load.

The main goal of the durability studies is to indicate whether fibre reinforced concrete exposed to a combination of mechanical and environmental load is less or more durable than concrete without fibres. Secondly, it is the aim to identify important mechanisms for the effect of the fibres on the durability. An overview of the research programme is given in [2].

This paper describes freeze-thaw and capillary water uptake tests, both intended for laboratory use, cf. Section 3. Investigations are made on cracked specimens after unloading (freeze-thaw) and on uncracked specimens (both methods), in order to investigate the effect of fibres and cracks. The capillary water uptake was applied after the freeze-thaw test to further analyse the effect of fibre reinforcement on the frost resistance. The concretes are compared with regard to frost resistance and water uptake.

2 Materials

The concrete referred to in this paper is named SA relating to the environmental class (more severe than aggressive). It has a water-powder ratio of 0.38 including both low-alkali sulphate-resisting cement (285 kg/m' concrete), fly ash (60 kg/m^3) and silica fume (on slurry basis) (24 kg/m^3). Fine aggregates (O-4 mm): 758 kg/m^3. Coarse aggregates: 535 kg/m^3 + 565 kg/m^3 (8-16 and 16-25 mm). Coarse aggregates are crushed rock. Air entrainment as well as plastizicers are included. Three different concretes were investigated: SA-0, SA-PP and SA-ZP, cf. Table 1. SA-0 is referring to a concrete without fibres.

Fibre	PP	ZP
Material	Polypropylene	Steel, hooked ends
Length	12mm	3omm
Cross-section	35 x 250-600 μm	d = 500 μm
Amount	1 .o vol%	0.4 vol%

Table 1 Fibres. Material, size, mount.

When adding fibres to the concrete mix a corresponding amount of coarse aggregates is removed. When adding PP-fibres also the amount of superplastizicer is adjusted and the amount of cement paste is increased 10% at the expense of coarse aggregates.

3 Test methods and test arrangements

Reinforced beams with dimensions 100x200x1150 mm are used as specimens. In the following the test setup for subjecting the beams to mechanical load as well as the methods for measuring the frost resistance and the water uptake are presented.

3.1 Mechanical load

A test setup has been developed to permit beams to be subjected to combined mechanical and environmental loads as described in [1]. Mechanical load is obtained by exposing the beams to 4-point bending, resulting in transverse cracks on the center part of the beam cf. [1]. The surface crack pattern is characterized using video-scanning and digital image analysis.

The beams were 5 months old at the time of testing. They were kept under water until they were loaded and crack widths were measured. The loading of the beams was carried out within 15 minutes. After unloading the crack widths were measured again and specimens for the freeze-thaw test were sawn fi-om the tensile side of the beams.

3.2 Freeze-thaw test

Every test consisted of four specimens from two different beams cast in separate batches. Three of the specimens were tested with one crack in the longitudinal direction of the specimen. One specimen was tested without cracks as a reference. The dimensions of the test specimens were 50x125x200 mm.

Testing was performed according to Swedish Standard SS 13 27 44 [3] at the Technological Institute in Taastrup. Before testing the specimens are covered according to Figure 1 and exposed to a 3 mm thick layer of 3% NaCl-solution, protected from evaporation with a plastic foil. The specimens are then exposed to freeze-thaw according to a specified temperature cycle [3]. After 7, 14, 28, 42 and 56 cycles the amount of scaled material [kg/m^2] is determined.

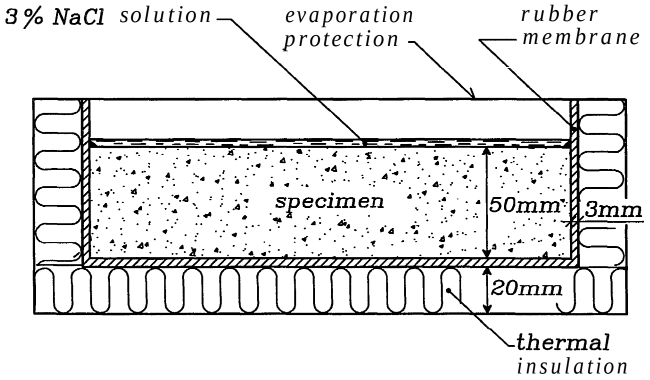

Figure I Test setup for freeze-thaw according to [3].

3.3 Water uptake

Capillary water uptake was applied on separate specimens after the freeze-thaw test to further analyse the effect of fibre reinforcement on the frost resistance.

Specimens were exposed to water using a RILEM method as described in [4]. The water uptake can be characterized by the amount of water, Q [kg/m^2], sucked up at the end of the test when the water uptake has almost ceased.

The water uptake tests are designed to study the effect of the temperature and the concentration of the salt solution. Tests are made at 20°C and 1°C with water or 3% NaCl-solution. Only the tests with water are treated in this paper.

Two 50x125x100 mm specimens from each concrete were prepared for each of the four exposure conditions. The specimens were sawn from the compression side of the beam, where no cracks are visible. Before the water uptake the specimens are stored at 50°C for 2 days and the vertical surfaces are sealed with paraffin wax to avoid evaporation.

4 Results

4.1 Freeze-thaw test

In Table 2 test results from the freeze-thaw test are shown as amount of scaled material [kg/m^2] after 56 cycles for all the specimens. Also the average crack widths [mm] measured in loaded state are given. After unloading the crack widths are reduced about 66%. In Table 2 the results are grouped according to the fact that specimens originates from two different batches.

SA-0		SA-PP		SA-ZP	
scaling [kg/m^2]	crack width [mm]	scaling [kg/m^2]	crack width [mm]	scaling [kg/m^2]	crack width [mm]
0.05 1	0.19	0.53	0.27	0.30	0.16
0.11	0.12	1.09	0.07	0.29	0.20
0.087	0.23	0.97	0.15	0.91	0.08
0.10	0	1.41	0	1.29	0

Table 2 Scaling after 56 freeze-thaw cycles and crack width in loaded state.

The development of scaling in [kg/m^2] during the freeze-thaw test is shown in Figure 2 (uncracked specimens) and Figure 3-5 (cracked specimens).

4.2 Capillary water uptake

Figures 6-8 show the average water uptake during two exposure conditions, cf. two different temperatures (20°C and 1°C) and pure water. Figure 9 shows results from an earlier study on water uptake at 20°C, [1].

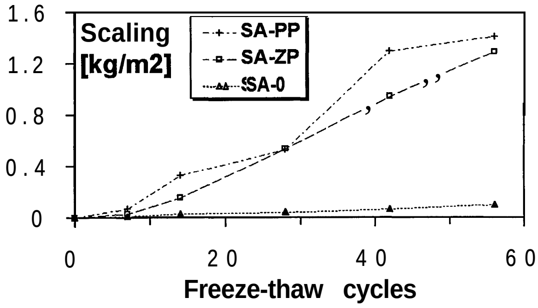

Figure 2 Scaling [kg/m²]. Uncracked specimens

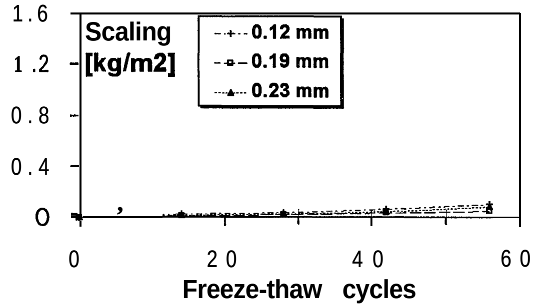

Figure 3 Scaling [kg/m²]. Cracked specimens. Concrete SA-0.

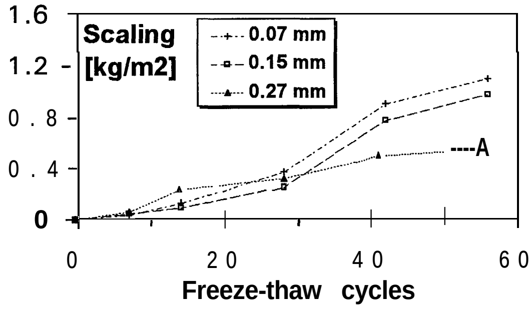

Figure 4 Scaling [kg/m²]. Cracked specimens. Concrete SA-PP.

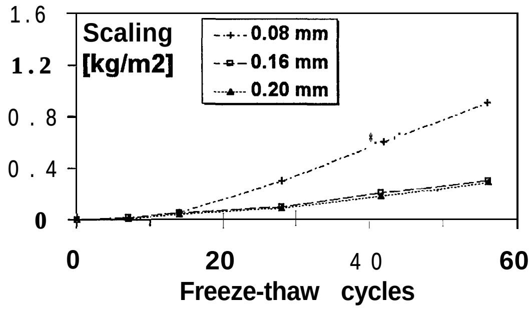

Figure 5 Scaling [kg/m²]. Cracked specimens. Concrete SA-ZP.

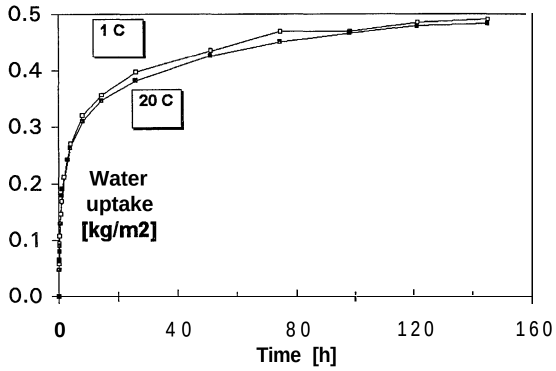

Figure 6 Capillary water uptake [kg/m²]. Concrete SA-0. Pure water. Average values.

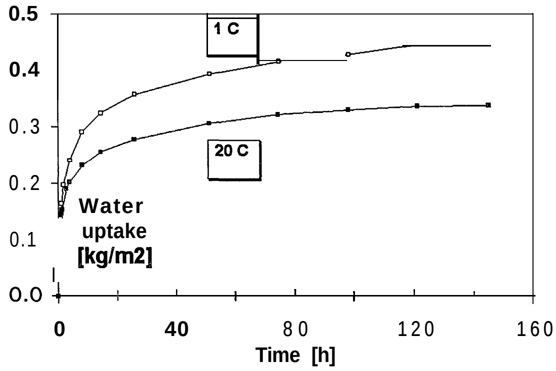

Figure 7 Capillary water uptake [kg/m²]. Concrete SA-PP. Pure water. Average values.

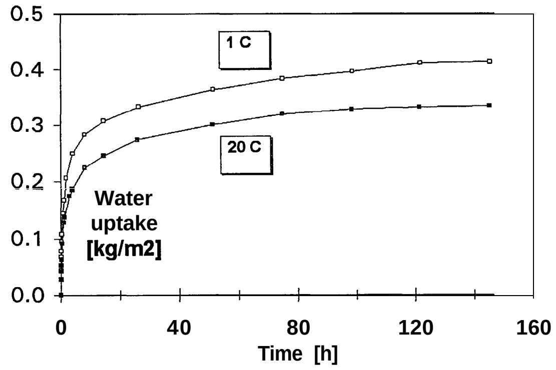

Figure 8 Capillary water uptake [kg/m²]. Concrete SA-ZP. Pure water. Average values.

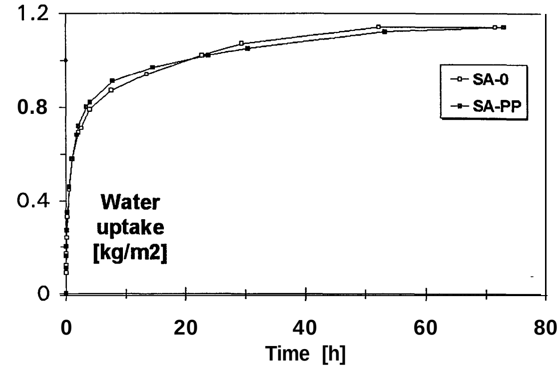

Figure 9 Capillary water uptake [kg/m²] at 20 C. Pure water. Results from [1].

5 Discussion

5.1 Freeze-thaw

According to Figure 2 and 3 SA-0 has a very good frost resistance since no specimen has more than 0. I kg/m² material scaled after 56 cycles. SA-PP shows a frost resistance on the border between acceptable and unacceptable and SA-ZP is characterized as acceptable (average value less than 1.0 kg/m² after 56 cycles). However, the results indicate that the scaling decreases when the crack width increases, especially for SA-ZP, cf. Table 2 and Figure 4. SA-ZP would be characterized as having a good frost resistance according to [3] if the upper two values in Table 2 originating from the same beam and with the largest crack widths are treated separately.

The fact that the specimens originates from different batches do not seem to explain the results. Neither the properties of the concrete in the fresh state nor the compressive strength after 28 days water curing indicates any differences between the batches.

While the concrete without fibres (SA-0) was designed for an air content of 5.5 vol%, the actual air contents measured in the fresh state by the pressure method were much lower: SA-0 4.2 vol%, SA-ZP 3 vol% and SA-PP 2.5 vol%. The results therefore emphasizes the need for a critical evaluation of the mix design and the mixing methods when designing FRC-structures. To be effective in relation to frost resistance not only the amount of air entrainment but also the stability of the air pore system is decisive.

Even when a satisfying air content is achieved (about 6 vol% for a concrete with water-cement-ratio 0.4-0.5) the PP-FRC normally behaves worse than plain concrete when tested according to [3] although it is having an acceptable frost resistance according to the test method, [5]. On the other hand, in more than one case it seems that the laboratory test has been to tough compared with experiences from natural weathering, [6].

In order to further analyse the freeze-thaw results it was attempted to investigate the effect of fibres on the durability of concrete by performing water uptake tests.

5.2 Water uptake

Comparing the results of the water uptake it seems that the water uptake in SA-PP and SA-ZP is dependent of the temperature and lower than in SA-0. The water uptake in SA-PP and SA-ZP is lowest at 20°C, about 30% lower than in plain concrete, based on the water uptake at the end of the test (145 h). At 1°C the water uptake is only 10-15 % lower than in plain concrete. This indicates that the addition of fibre reinforcement and a reduction of the temperature uptake has opposite effects on the water uptake. Normally entrained air will absorb water very slowly because of the size of the air pores Therefore differences in air content between the concretes can only explain differences in water uptake as measured within four days, cf. Figures 6-8, if the existence of fibres have a (negative) effect on the air pore system .

Only very few specimens are involved and the variation of some of the test series is quite large. Therefore the results has to be taken more as an indication of the effect of fibres and temperature on the water uptake. Actually earlier tests showed no effect of PP-fibres on the water uptake at 20°C as shown in Figure 9. 'The concretes had the same air content as in the current tests. Therefore it is necessary to study the pore structure of the concretes to encircle the mechanisms involved when FRC are exposed to freeze-thaw or water uptake.

5.3 Mechanisms

In an earlier study of the long term performance of FRC it was shown that the PP-FRC had a larger length deformation and a higher degree of micro cracking after freeze-thaw exposure than concretes with other fibres (steel, glass etc.). Analysis of surfaces of fracture showed unsatisfactory bond between fibres and matrix [7].

Compared to steel fibres PP-fibres have a lower bond strength to the cement matrix, [8] which could explain the higher scaling. During the freezing phase the pressure from the water could eventually loosen the PP-fibres from the matrix thereby open the material for more water and thereby accelerating the degradation.

If a PP-fiber has the possibility to loosen from the cement paste then a small canal can theoretically be created between the fiber and the paste. This is due to the fact that the thermal expansion coefficient of PP-fibres is ten times higher than for concrete ($100 \cdot 10^{-6}\,C^{-1}$ vs. $10 \cdot 10^{-6}\,C^{-1}$). However, a temperature change from 20°C to 1°C will only reduce the diameter of the PP-fiber with 0.2%. This reduction is much to small to explain the higher water uptake at 1°C compared with 20°C. On the other hand, canals could open the pore system and thereby increase the connectivity. The real problems in this argumentation are 1) why is the water uptake in SA-0 then even larger than in SA-PP no matter what temperature, 2) the hypothesis can not be applied to ZP-FRC since steel has a thermal expansion coefficient comparable to concrete.

6 Concluding remarks

According to the freeze-thaw tests the FRCs are less durable than plain concrete, primarily because the FRCs have a lower amount of air entrainment Addition of fibres reduces the crack width since the FRC-beams were subjected to 20-30% higher load than plain concrete before the freeze-thaw tests in order to achieve corresponding crack widths. PP-fibres results in higher scaling than ZP-fibres which can be related to lower bond strength between fibres and matrix.

The water uptake of FRC depends on thetemperature. At 1°C the water uptake is 20-30% higher than at 20°C. Only in concrete with PP-fibres this can be related to different thermal expansion coefficients between fibres and matrix. Therefore studies of the pore structure must be made to identify mechanisms for the effect of the fibres on the durability.

Further investigations should also include new freeze-thaw tests on concretes with comparable amounts of air entrainment to separate the effect of the amount of air entrainment from the effect of fibre reinforcement on the frost resistance. Finally, the repeatability of the water uptake results should be verified.

7 Acknowledgements

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8 References

1. Hansen, E.J. de Place and Nielsen, L. (1997) Durability of cracked fibre reinforced concrete structures. pp. 145- *152 in: Advanced Design for -Concrete Structures.* Gylltoft, Engström, Nilsson, Wiberg and Åhman (Eds.). Symp. held at Chalmers University of Technology, Göteborg, june 12- 14, 1997. A publication of Int. Center for Numerical Methods in Eng. (CIMNE), Barcelona 1997.

2. Hansen, E.J. de Place and Hansen, K.K. (1996) Durability of fibre reinforced concrete structures. *Proc. Nordic Concrete Research Meeting,* Espoo, Finland 1996, pp.277-278.

3. *SS 13 72 44* (1995) *Concrete testing - Hardened concrete - Scaling at freezing (in* Swedish). SS 13 72 44, 3.udgave. Standardiseringen i Sverige, mar 1995.

4. Fagerlund, G. (1977) The critical degree of saturation method of assessing the freeze/ thaw resistance of concrete. *Materials and Structures,* vol. 10, no.58, pp.217-253.

5. Larsen, E.S. *(1992) Service life prediction and fibre reinforced cementitious composites.* PhD-thesis. SBI Report 222, Danish Building Research Institute, Hørsholm.

6. Glavind M. (1993) *Fibre reinforced concrete* (in Danish). Materials Technology Development Progr. (MUP 1) 1989-92. Danish Technological Institute, Taastrup.

7. Strabo, F. et al. (1987) *Long term durability of concrete with polymeric fibres (in* Danish). Technological Institute, Tåstrup, Denmark.

8. Rasmussen, T.V. *(1997) Time dependent interfacial parameters in cementitious composite materials.* Ph.D.thesis. Series R no. 33, Dep. of Structural Engineering and Materials, Technical University of Denmark.

Hydraulic conductivity of combiliners in solid-waste landfills

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Abstract

A combiliner is a combination of a geomembrane with a geosynthetic clayliner or a geomembrane with a layer of compacted clay or with sand-bentonite. The paper deals with the hydraulic conductivity or resistance of geomembrane/clayliner combinations. These thin liners are easier to apply, save space and are more economical. However, they are sensitive to local damages like fissures and pinholes, which might have drastic influence on the sealing properties, so that protection of the environment is no longer guaranteed. Since perfect contact between the clayliner and the overlying geomembrane is impossible, a small space exists between them. This space is called interface and its properties affect the water flow through a damaged combiliner.

A mathematical model for the flow through a damaged combiliner is based on the second order differential equation describing the flow. The flow depends on two important properties of the components: the hydraulic resistance of the geosynthetic clayliner and the transmissivity of the interface. They depend on several parameters: the effective compressive stress on the combiliner, the kind of leachate that is flowing, the hydraulic head,. . . Also the size and the shape of the flaw in the geomembrane influence the flow. This paper examines the influence of the compressive stress in more detail.

It presents a manner to derive the relationship between the compressive stress and the transmissivity of the interface. Therefore the differential equation is solved, using results of laboratory experiments. These experiments are carried out in large-size permeameters, at variable compressive stress levels on the combiliner. As a result of the calculations it will be possible to predict the transmissivity of the interface when the compressive stress is known.

This research is a preliminary phase in the construction of a complete mathematical model for the flow through damaged combiliners.

Keywords: clayliner, geomembrane, geosynthetic composite, hydraulic conductivity, pollution

1. Introduction

The hydraulic resistance levels of the bottom and top leakage protection systems of waste disposal sites in Flanders are prescribed in the Flemish Regulation for Environmental Protection VLAREM II [1]. Several systems are proposed to meet this requirement. This paper deals with combiliners (a combination of a geomembrane and a geosynthetic clay liner (GCL)). This cover system has several advantages in comparison to other cover systems. A thick layer of compacted clay (CCL), for example, does not serve its purpose in case of differential settlements or desiccation that cause cracks and loss of water tightness. The use of only a geomembrane as a cover system is limited because it is vulnerable to punctures. A geomembrane overlying a CCL protects the clay liner from desiccation from above, but differential settlements, punctures and the installation of the layer still cause big problems.

The major advantages of the use of combiliners (geomembrane + GCL) are [2], [3], [4]: an easy and rapid installation; a guaranteed quality, since the components are prefabricated; the clay in the GCL is bentonite, which has self-healing capacities in case of puncture; since the GCLs are thin (10 mm), more volume is available for waste [5]; the cover is rather easy to repair; both components can be anchored at the top of the site's slopes if necessary.

Disadvantages are [2] : potential slippage between both components; vulnerability to punctures; low shear strength of the hydrated clay.

The low shear strength of the GCL is improved by the 'needle-punching' system [4], [6]: the bentonite is sandwiched between woven and nonwoven geotextiles connected by fibre piles. This prestressing effect gives a higher shear strength and a capacity of self healing in case of puncture. Since the fibre piles prevent the vertical swelling of the bentonite, it can swell laterally in case of puncture which results in a self healing effect.

The major problem with combiliners is the fact that they are often damaged [7]. The causes of damage can be distinguished in three categories: mechanical causes (differential settlements, vehicular traffic during installation, punctures from underlying waste, creep,...); biological (by burrowing animals) and chemical damage (reactions with leachate, ultraviolet light, aging,...); damage due to improper seaming during construction [7], [8], [9].

Because of potential damage composite action between the geomembrane and the GCL is required to guarantee a cover with a sufficiently high hydraulic resistance. However, this resistance no longer goes to infinity, because the absorption capacity of the composite is limited. The question to be answered is: what is the remaining hydraulic resistance in the short and long run of a damaged combiliner and by what is it affected?

The development of a mathematical model for the flow through a damaged combiliner requires results of permeability tests. These tests are carried out in large-size permeameters.

2. Mathematical model for the flow through a damaged combiliner

A damaged combiliner can be modelled by three layers (Figure 1): the overlying geomembrane (with a flaw), the GCL and the interface between them. This layer is present because perfect contact between the geomembrane and the GCL is impossible (wrinkles in the geomembrane, irregularities between the geomembrane and the GCL,...[8]).

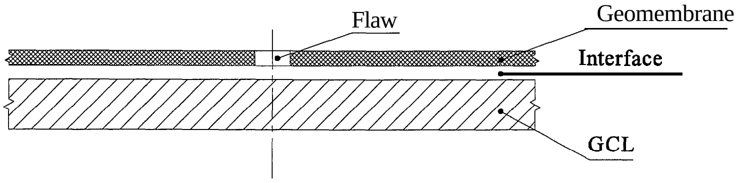

Fig. 1: Model of a damaged combiliner

When water flows through the flaw in the geomembrane, lateral flow occurs in the interface, with simultaneous infiltration into the GCL. This leads to the model shown in Figure 2. The amount of water that flows through the combiliner depends on the

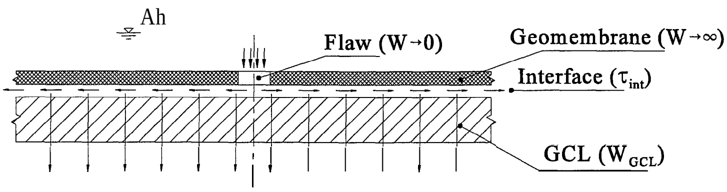

Fig. 2: Model of the flow through a damaged combiliner

hydraulic properties of the components. These properties are not constant, but depend on the conditions in situ. It is necessary to investigate the influence of these conditions on the effectiveness of the cover system. The components of the model will be described hereafter. The factors affecting their properties are pointed out.

The upper layer is the geomembrane. Ideally its hydraulic conductivity is zero, but because of damages and improper seaming flow is possible. The flaws are considered to be perfectly permeable. This means that there is no loss of hydraulic head due to flow through the flaw [7], [8], [9]. The geomembrane itself is assumed to have a hydraulic conductivity equal to zero, which means that diffusive fluxes are not considered. However, permeation can be an important factor in some cases [S]. The type of geomembrane, the size and the shape of the flaw are parameters to be observed.

The GCL can be described by its hydraulic resistance W_{GCL}. W_{GCL} is defined by the ratio of the thickness d_{GCL} to the hydraulic conductivity k_{GCL}:

$$W_{GCL} = \frac{d_{GCL}}{k_{GCL}} \tag{1}$$

W_{GCL} depends on the compressive stress on the combiliner, the kind of leachate (dissolved ions, affecting the behaviour of the bentonite) and the hydraulic head on top of the GCE. Research in the Reyntjens Laboratory [10] resulted in a formula describing the relation between the mean effective compressive stress on the GCL σ_{GCL} (in kPa) and W_{GCL} (in days):

$$W_{GCL} = 1\,960 \times (\sigma_{GCL})^{0.491} \qquad (2)$$

This formula has been derived on the basis of a small number of experiments on Bentomat® GCLs. The leachate was tap water from the city of Leuven. The results of formula (2) are compared with results of other researchers. For σ_{GCL} = 9 kPa, [6] obtains k_{GCL} = 4.10^{-12} m/s for a Bentomat® GCL (thickness 9.4 mm). This means a hydraulic resistance of 27200 days. With formula (2) this would be 5765 days. Formula (2) seems to underestimate the hydraulic resistance. Comparison with [11] seems to confirm formula (2): for σ_{GCL} = 3 5 kPa, k_{GCL} = 1.1 0^{-11} m/s (W_{GCL} = 11574 days with d_{GCL} = 10 mm). Formula (2) gives for σ_{GCL} = 35 kPa: W_{GCL} = 11230 days.

The interface is modelled by its transmissivity τ_{int}. τ_{int} is defined as the product of the thickness d_{int} and the hydraulic conductivity k_{int} of the interface:

$$\tau_{int} = d_{int} \times k_{int} \qquad (3)$$

[12] shows that the transmissivity has an important effect on the flow rate through the combiliner, much more than the size of the flaw or k_{GCL}. It is clear that τ_{int} depends on the compressive stress on the combiliner, since this influences the thickness of the interface. Particularly this relationship is examined in the experiments presented in this paper. Other parameters are the amount and the type of bentonite in the interface, the type of geomembrane, the type of GCL (determines the type of geotextile), the water pressure, the presence of waves or wrinkles in the geomembrane and possibly the kind of leachate that is flowing.

The flow shown in Figure 2 can be described by a differential equation of the second order as a function of the water pressure in the interface (h_{int}) [8] (see also Figure 3):

$$r\frac{d}{dr}\left(\tau_{int}\frac{dh_{int}}{dr}\right) + \tau_{int}\frac{dh_{int}}{dr} - rh_{int}\frac{1}{W_{GCL}} = 0 \qquad (4)$$

τ_{int} and W_{GCL} are dependent on h_{int}. h_{int} itself is not constant for the whole interface: under the flaw h_{int} is equal to the hydraulic head above the combiliner (Ah), but further away from the defect h_{int} becomes smaller, until it reaches zero. This means that there is no difference in water pressure above and under the GCL. Figure 3 shows the variation of h_{int} with the distance from the center of the pinhole: $h_{int}(r)$. The distance at which h_{int} is zero is called the radius of the wetted area (R). Flow occurs only in the wetted area because only there hydraulic gradients are present: laterally in the interface and vertically on the GCL.

3. Required data

The differential equation (4) is given as a function of τ_{int}, W_{GCL} and $h_{int}(r)$. τ_{int} and W_{GCL} can be written as a function of the effective compressive stress on the components.

For W_{GCL} formula (2) is used. A similar expression is assumed for τ_{int} (with τ_{int} in m^2/s and σ_{int} in kPa) [13]:

$$\tau_{int} = a \times (\sigma_{int})^b \qquad (5)$$

In equations (2) and (5), σ_{GCL} and σ_{int} are no constants: they depend on the distance from the flaw, because $h_{int}(r)$ is not constant.

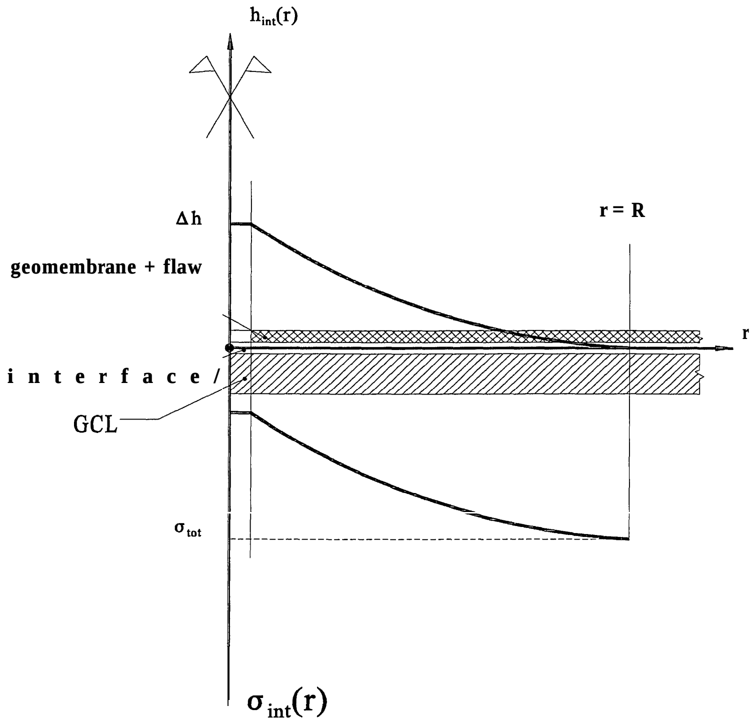

Fig. 3: The variation of h_{int} and σ_{int} in the interface

The unknowns in the differential equation of second order become a, b and $h_{int}(r)$. Since τ_{int} decreases when σ_{int} increases, b is assumed to be equal to -1 as a first approximation. To solve the-equation the real flow through the flaw should be determined experimentally.

4. Experimental program

The aim of the experiments is to measure the amount of water that flows through a damaged combiliner. Therefore, six permeameters with a diameter of 300 mm are installed in the Reyntjens Laboratory. These permeameters are equipped with hydraulic jacks to obtain the desired value of σ_{tot}. In this stadium of the research only the influence of σ_{tot} is being investigated, but further research will observe the other parameters (the size and shape of the flaw, the kind of leachate, the water head,. . ..).

The permeameter is shown in Figure 4. In this configuration water cannot flow along the edges of the geomembrane: the flow is forced to pass through the flaw. The GCL is smaller than the geomembrane, so that water can flow freely out of the interface. The measured amount of water is composed of the amount that has flowed through the GCL and the amount coming from the interface. The sum is equal to the flow through the flaw.

Since the GCE is hydrated before the measurements start, only the steady flow conditions are considered. This is a worst-case scenario: when the GCL is not saturated, flow in the GCL will lead to saturation and swelling of the GCL instead of flowing

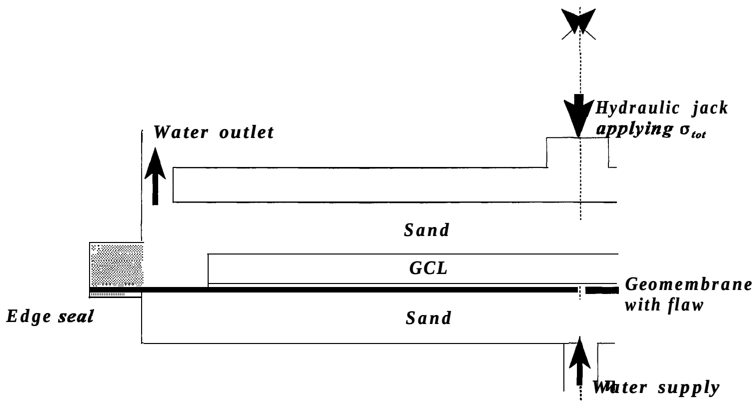

Fig. 4: Permeameter used in the laboratory

through it [14]. However, attention must be paid to situations where the GCL is hydrated with other liquids than water: the hydraulic resistance can be much lower in these cases [15].

5. Interface transmissivity

After installing the combiliner in the permeameter, loading and hydrating it, the measurements can be started. Measurements are continued until the measured water flow remains constant, indicating that the state of equilibrium for the given σ_{tot} is reached. σ_{tot} is then increased and measurements are continued until a new equilibrium is achieved, etc.

For each value of σ_{tot} the differential equation (4) can be solved, obtaining $h_{int}(r)$ and the coefficient a in

$$\tau_{int} = a \times (\sigma_{int})^{-1} \qquad (6)$$

Since σ_{int} is a function of r, τ_{int} also depends on r. A general value of τ_{int} is obtained by taking the area-mean value of $\tau_{int}(r)$: $\tau_{int\ m}$.

When $h_{int}(r)$ is known, $\sigma_{int}(r)$ can be calculated and an area-mean value $\sigma_{int,m}$ is obtained. By putting the values of $\tau_{int,m}$ in a graph with the representative values of $\sigma_{int.m}$, one can evaluate the dependence of $\tau_{int,m}$ on $\sigma_{int,m}$ (Figure 5). The data are fitted with a function of the form

$$\tau_{int,m} = c \times (\sigma_{int,m})^{d} \qquad (7)$$

The following values are obtained:

c = 2.30 10^{-10}

d = -0.71

These results are for a combiliner composed of a HDPE geomembrane with a thickness of 2.5 mm and a GCE with a thickness of 10 mm (Bentomat®). The flaw was a circular hole with a diameter of 10 mm, Ah was 1 m and the leachate was tap water.

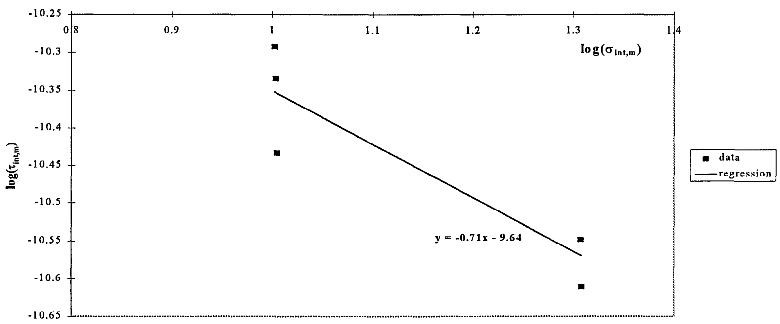

Fig. 5: $\tau_{int,m}$ as a function of $\sigma_{int,m}$

With this results, it is possible to predict the value of $\tau_{int.m}$ for a given value of the compressive stress on the combiliner. The flow through the combiliner can be calculated using the obtained value of $\tau_{int.m}$ in the differential equation (the reverse procedure). This leads to a mathematical model for the flow through a damaged combiliner.

This model is a model for a combiliner in a permeameter: the wetted area is as large as the GCL. In reality the wetted area is larger: [9] obtains values of R varying between 30 and 90 cm, depending on the diameter of the pinhole, k_{GCL} and Ah. If the aim is to make a model for a damaged combiliner under field conditions, it is necessary to take into account this important difference.

The value of d in formula (7) (d=-0.71) is in contrast with the value of b in formula (3) (b=-1). The latter one was just an assumption. The solution of the differential equation should be redone with b=-0.71 as a better assumption. An other remark is that this procedure is based on a limited number of preliminary tests. More test results are required to verify the values in formula (7). The application of it must be done with care, because a number of questions still have to be answered.

6. Conclusions

Solving the second order differential equation makes it possible to evaluate the transmissivity of the interface between the geomembrane and the GCL. The solution of the equation requires results of laboratory tests in large-size permeameters. A reliable prediction of the transmissivity in terms of the compressive stress can be made if enough results are available. The influence of other parameters will be investigated in coming research, leading to a model for the flow through combiliners. The results of this model can be compared with results coming from field measurements on combiliners. Such project is still in progress. The behaviour of a cover system for a waste disposal site with steep slopes (45 °) in Antwerp (Belgium) is investigated. The major problem with such steep slopes is the stability of the top layers. There is a relation between the stability of the cover and its water content [13]: a saturated layer is less stable than an unsaturated one. The failing of a drainage layer can endanger the stability of the slopes. A model for the flow through the cover system is useful in dimensioning the drainage layers and thus ensuring the stability.

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8. References

1. Heyman, J., Smout L. (1997) Milieuwetboek VLAREM II, Kluwer Rechtswetenschappen België
2. Daniel, D.E., Koerner R.M. (1993) Cover Systems, *Geotechnical practice for waste disposal* (ed. D. E. Daniel), Chapman & Hall, London, pp. 455-96
3. Van der Linden, E. (1993) De prefab bentonietmat als minerale bovenafdichting van afvalstortterreinen, NIRIA Symposium Bovenafdichtingen stortplaatsen, Provinciehuis Noord-Brabant 's Hertogenbosch (2 1.04.93)
4. Eith, A.W., Boschuk J., Koemer, R.M. (1991) Prefabricated bentonite clay liners. *Geotextiles and geomembranes* 10, pp. 575-99
5. Derian, L., Gharios K.M., Kavazanjian, E., Snow, M.S. (1993) Geosynthetics conquer the landfill law. *Civil Engineering,* Dec. 1993, pp. 50-53
6. Estornell, P., Daniel, D.E (1992) Hydraulic conductivity of three geosynthetic clay liners. *Journal of Geotechnical Engineering,* Vol. 118, No 10, October 1992, pp. 1592-1606
7. Walton, J., Rahman, M., Casey, D., Picornell, M., Johnson, F. (1997) Leakage through flaws in geomembrane liners. *Journal of Geotechnical and Geoenvironmental Engineering,* Vol. 123, No 6, June 1997, pp. 534-39
8. Giroud, J.P., Bonaparte, R. (1989) Leakage through liners constructed with geomembranes - Composite liners. *Geotextiles and Geomembranes,* pp. 7 1- 111
9. Brown, K.W., Thomas, J.C., Lytton, R.L., Jayawickrama, P., Bahrt, SC. (1987) Quantification of leak rates through holes in landfill liners, Report prepared for US Environmental Protection Agency EPA/600/2-87/062
10. Van Gemert, D., Verwaest, T. (1996) Waterdoorlatendheid van bentonietmatten en combiliners - eindverslag, K.U.Leuven Research and Development, Laboratorium Reyntjens, Report P.V. : R/28092/96
11. CETCO (1991) Final Report Laboratory Testing of Bentomat (TR 101)
12. Wilson-Fahmy, R.F., Koemer, R.M. (1995) Leakage rates through holes in geomembranes overlying geosynthetic clay liners. *Geosynthetics '95* pp.655-68
13. Guldentops, K., Willocx, R. (1997) Afdek van afvaldeponieën onder steile helling - modellering van de waterhuishouding, Thesis K.U.Leuven, Dept. of Civil Engineering
14. Mazzieri, F., Pasqualini, E. (1997) Experimental results on hydraulic behaviour of a GCE. *Proceedings of the 14th International Conference on Soil Mechanics and Foundation Engineering, Hamburg 1997,* Vol. 3, pp. 1919-22
15. CETCO (1993) Bentomat Specification Guidelines (TR 403)

Durability of Building Materials and Components in Agricultural Environment

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Abstract

The agricultural environment has its main influence on floor surfaces in buildings and structures. The floor surfaces are exposed to a chemical and physical environment, which is very aggressive, because of different factors originating from manure, drinking water and feed stuff.

Floors and other building components of farm buildings show different degrees of degradation. Concrete material, which is often used in floors and walls need a high material quality to resist against the chemical and physical attacks.

This paper will present a brief review of recently performed research about durability of building materials and components in agricultural environment.
Keywords: Farm buildings, agricultural environment, durability, concrete material, wood material, steel material.

1 Introduction

In agricultural production one can roughly distinguish between the following types of farm buildings: 1) animal houses for cattle, pigs and poultry 2) slurry pits and silos for manure and 3) storage structures for agricultural products.

Farm buildings are built of different materials and components, such as concrete material (floor and foundation structures); concrete, steel or wood materials (wall structures) and steel or wood materials (roof structures).

The agricultural environment, both inside and otside farm buildings, is very aggressive. The biological activity in organic matter produces aggressive substances towards building materials as well as towards animals and persons. It is especially the chemical environment, which influences the building materials. Inorganic and organic acids, natural manure and different salts of artifical manure products have a great impact on the durability of building materials and components in farm buildings.

Research about durability of building materials and components in agricultural environment has been focused on concrete for agricultural purposes. Most of this research has been carried out at different institutes and universities in Belgium, Ireland, the Netherlands and Sweden. Within the organisation European Agricultural Engineers (EurAgEng) a working group (SG15/TG1) was formed in 1996 with the aim to put together performed research and plan for new research activities within this area of durability research.

This paper will present a review of recently performed research about durability of building materials and components in agricultural environment.

2 Agricultural environment

2.1 Animal houses

The chemical and physical environment of animal houses can be divided into two distinct parts: 1) the air environment and 2) the wet environment on floors, walls and equipment.

The *air environment* depends on a wide variety of influences, such as the characteristics of the housing system (layout and volume of the building, type of roof, thermal insulation, ventilation, handling of manure), the types of animals housed and the physical environment (sun radiation, temperature, air speed, relative humidity). There are a large number of gases in the air environment but most of them occur in low concentrations. The presence of manure also considerably influences the air environment.

Table 1 presents the recommended maximum concentrations of the gases in stables, which occur in the highest concentrations. Measurements of concentrations of ammonia and carbondioxide at floor level up to 0.3 m above floor level demonstrated the following [1]:

- NH_3 concentrations range from 2 – 50 ppm (yearly mean: 4 – 13 ppm);
- NH_3 and CO_2 concentrations are considerably lower during summer periods than in winter periods;
- the use of natural or mechanical ventilation has no significant influence on NH_3 and CO_2 concentrations. Too low ventilation rates cause an increase of especially the CO_2 concentration;

The content of dust from animal houses originates primarily from the animals, the fodder, the straw material and the manure.

Table 1. Recommended maximum concentrations of gases and dust in stables [1].

Gas /dust	Concentration
CO_2	3000 ppm
CH_4	500 ppm
H_2S	0.5 ppm
NH_3	20 ppm
dust	1.5 mg/m^3

The acceptable range of air temperature strongly depends on the type of animal housed Table 2 contains acceptable temperature ranges for housing systems. These temperatures are valid for a zone ranging from floor level to 0.3 m above floor level. The floor is assumed to be dry, not heated and made of concrete.

Table 2. Acceptable extreme temperatures in housing systems for animals [1, 2, 3].

Animals	Temperature [^0C]
dairy cattle, fattening bull	5 - 20
young cattle< 1 yr	10 – 24
pigs < 20 kg	23 – 33
fattening pigs	17-25
sows	12-25
broilers < 2 months	17 – 33
broilers	15-22
laying hens	15-22

The highest concentrations of aggressive substances are found in the wet *environment*t on the floors in animal houses. The wet environment consists of minerals and salts of different species. It has been concluded at analysing the chemical composition of manure and silage that the highest concentrations of chloride has been found in poultry manure, 0,34 % and the lowest has been found in cattle manure, 0,05 % [4] .

The wet environment on the floors in animal houses also consists of high concentrations of organic acids. It has been concluded at analysing the chemical composition of samples of organic matter from different places in houses for pigs, cattle and poultry, that there are concentrations of acetic acids up to 8 %. The acid concentrations seem to increase when the time for the fermentation process in the organic matter increases [4] .

2.2 Manure and silage storage systems

Three types of *manure* can be distinguished:

1. Liquid manure, which contains urine with a maximum dry matter content of 3%.
2. Slurry, which is a mixture of urine, faeces, feed residues and water. The slurry has to be regularly mixed to facilitate pumping from the storage. The dry matter content is 2-20%. Table 3 contains information on the chemical composition of slurry from three animal categories.
3. Solid manure, in which about 90-95% of the nitrogen is organically bound. This is only 30-50% and about 5% for slurry and liquid manure respectively [2].

Table 3. Chemical composition of slurry, in g/l [5].

Chemical component	Cattle	Fattening pigs	Laying hens
Nitrogen (N-Kj)	3.8 - 7.6	4.3 - 11.5	5.9 - 15.7
Ammonium (NH,-N)	0.2 - 4.4	1.3 - 5.5	2.6 - 9.2
Phosphate (P_2O_5)	1.3 - 3.1	3.6 - 6.6	0.3 - 12.0
K_2O	3.3 – 11.0	2.0 - 6.1	0.3 - 11.5
CaO	1.6 - 3.3	2.4 - 4.4	0.9 - 19.6
MgO	0.8 - 1.6	0.6 - 2.0	0.1 - 2.4
Cl^-	1.8 - 4.2	0.6 - 3.3	0.1 - 3.2
SO_4^{2-}	2.0 - 3.0	1.0 - 2.0	2.0 - 4.0
Acetic acid	5.5 - 7.0	3.2 - 11.0	11.0 - 22.0
Propionic acid	1.6 - 2.0	0.7 - 3.0	4.0 - 7.5
PH	7.0 - 8.8	7.3 - 8.6	6.7 - 8.3
Dry matter (% m/m)	7 - 9	4 - 11	11- 18

Most *silage* is stored on concrete, either in bunker silos (base slab plus walls) or on a base slab only. The dry matter content of fresh, compacted silage is about 18-24% . The quantities of silage effluent coming out of the fresh silage can be up to 200 1 per ton of silage (pressed pulp: 10-50 l/ton; maize: 50-100 l/ton; brewer’s grains: 100-150 l/ton; wet grass: 100-200 l/ton). The effluent produced during storage of e.g. grass and maize is drained towards the front of the base slab, collected and pumped into a slurry pit [6, 7, 8]. The pH value of the effluent can be 3.5 - 4, the main acids being lactic and acetic acid.

Fertilizer can also be stored on slabs. It may contain considerable amounts of nitrogen (up to 25%), phosphate (P_2O_5; up to 45%), potassium (K_2O; up to 60%), calcium (CaO; up to 55%), manganese (MgO; up to 25%) and sodium (NaO; up to 5%). In horticulture, liquid fertilizers containing e.g. Ca^{2+}, Mg^{2+}, K^+, PO_4^{3-}, SO_4^{2-}, CO_3^{2-} or NO_3^- are increasingly being used [9].

Potatoes are stored at temperatures of about 5 ^{0}C and treated with fungicides containing acids or chlorides. Germination retardents contain chloride. Resistance against mechanic loading, for instance by loading by lift trucks, should be taken into account.

3 Durability of Building Materials and Components

3.1 Floor Structures

In animal houses there are three main types of floors; solid floors, unperforated floors that are laid directly on the ground and slatted floors, which permit drainage of urine and faeces from the animals [10] . The major advantages of slatted floors are the complete omission of straw and an appreciable reduction in labour time requirment for cleaning of the floor. The animals are cleaner because of the fast removal of the manure and areas of possible reduction in the immediate vicinity of the animals are eliminated [1 1] .

These floor types are all made of concrete material. The solid and unperforated types are mostly made of ready mix concrete but the slatted types (slatted beams and cassettes) are mainly made of precast concrete. In 1991 work was started to establish an European standard [12] for slats, such as single beams, twin slats, multiple slats and perforated panels. The standard classifies the slats according to cattle on one hand and pigs, sheep and goats on the other hand. Requirments are given for concrete compounds, concrete strength, concrete quality, position of the reinforcement, floor slats geometry and surface characteristics.

According to the european standard the demands of the concrete quality for floor slats are that the water/cement ratio should not exceed 0,45 and the cement content should not be less than 350 kg/m^3 at a concrete cover ≥ 40 mm.

Degradation

Several field investigations have shown severe degradation on concrete slats [13, 14] .The degradation of the concrete material is due to the aggressive environment on the floors in the animal houses. It has been concluded that there are three main degradation mechanisms; the influence of the organic acids as lactic and acetic acid, the reinforcement corrosion and the mechanical wear.

Most of *the organic acids,* especially acetic acid come from the manure. The lactic acid originate from acidified meal/water mixtures and is therefore the main source of severe concrete degradation near or in between the feed and water supply.

Lactic and acetic acid are very aggressive, because their reaction with free lime of the concrete produces very soluble calcium salts [15] . When those salts are leached, the concrete porosity will increase and the pH in the pores will decrease. Following factors, besides water/cement ratio and cement content, influence on the degradation of concrete by lactic and acetic acid; 1) cement type, 2) aggregate type, 3) addition of fly ash or silica fume, 4) addition of polymers, 5) application of cement-bound surface layer and 6) impregnation.

Reinforcement corrosion is an important degradation mechanism for floor slats of concrete material. High concentrations of carbondioxide in dairy farms may give rise to carbonation of concrete slats. In general the risk of chloride initiated corrosion in floors is higher than the risk of carbonation initiated corrossion because of the high cloride content found in floors of farm buildings [13] . The high chloride content may arise from manure and feed residues and sometimes from accelerators used in the concrete.

Mechanical wear occurs on floors in animal houses. Because of the mechanical wear the floors of animal houses may become too slippery, which may result in paw disorders. It has been suggested a concrete floor with a regular hexagonal pattern in order to improve the slippery safety [16] .

3.2 Wall Structures

Farm buildings are mostly designed as industrial buildings with structural systems of stone, brick, timber or steel material. Structural systems of stone or brick in old farm buildings are covered on the inside and outside by painted plaster systems. The structural systems of timber and steel are usually covered by wood fibre and hardened gypsum boards or steel sheets, when new buildings are designed.

The equipment inside animal houses often consists of steel, zinc and aluminium structures combined with wood fibre and cement based boards. The equipment is often made of bad quality because it will rather often be changed depending on the animal production.

Wall structures of manure and silage storages are mostly made of concrete material. Especially wall structures for silage storage structures are often painted on the inside as environmental protection.

Degradation

Field studies of corrosion in houses for fattening pigs have shown severe attacks on the lower parts of the equipment (Figure 1). The massloss has been measured to 200 and 50 µm/year for steel and zinc structures respectively. Corrosion attack on aluminium structures are very severe in pig houses on those points where manure and feed have gathered.The attacks are not spread evenly over the material surface but are concentrated on special points [17].

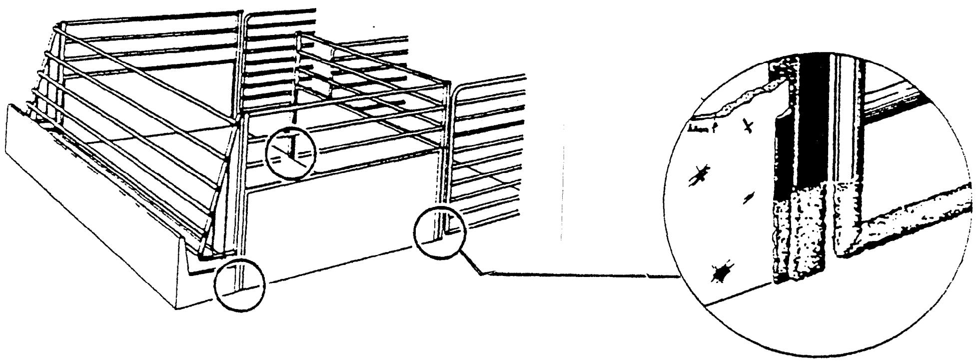

Figure 1. Example of building components in pens for fattening pigs with high risk of corrosion [17].

Micro biological corrosion may occur in agricultural environment. Such corrosion occur under anaerobic circumstances and neutral pH-values. The cause is mainly sulphate reducing microbes. Steel structures for covering manure tanks have been exposed to this type of corrosion [18].

Timber walls in farm buildings are protected against biological degradation by constructive design and by applying chemical preservatives. The recommendation is to design against degradation before using wood treated with chemicals.

Fungi are the biological degradation that cause most damages in farm buildings. It is the decay producing fungi that are worst because they reduce the strength by removing lignin and cellulose [19].

3.3 Roof Structures

Today steel compete hard with timber as a structural material for roof structures of farm buildings. Principally the roof construction consists of either beams supported by hinged or fixed posts or rafters supported by posts in combination with girders. In farm buildings post and beam timber structures range up to 25-30 m span and they can be very cost effective for spans between 7 and 20 m [19] .

The ceiling constructions can be an insulated ceiling with wood-based panels or spaced boardings as cladding material. A breathing ceiling with air inlet through the insulation is comfortable when spreading the air into the pens. Insulated parallel roofs of self-supporting elements are effektive to create good air volumes for the animals. Uninsulated roofs are usually made of steel sheets or glas fibre board sheets.

Degradation

Degradation of roof structures in animal houses mostly concerns the inner surface of insulated ceilings. Because of high air humidity the unpainted steel sheets corrode very fast. Unpainted steel sheets also-corrode very fast on the surface faced to the outside climate.Wood-based panels often show mould on the inner surface of the ceiling.

4 Discussion

The environment in buildings and structures used in agriculture consist of many different factors. There are handled large amounts of organic material such as different feed stuff and manure, which leads to high biological activites especially inside animal houses. The micro biological activities cause creation of organic acids. Inside animal houses high humidities and varying temperatures often occurs.

Because of the aggressive physical and chemical agricultural environment building materials and components deteriorate very fast and this is very costfull for the agricultural sector. This is a major problem concerning the durability of building materials and components in farm buildings.

In the future it is important to investigate the chemical and physical environment more intensively in the most exposed places of farm buildings. This knowledge can be used as a tool at choosing material and components with prolonged durability.

5 Conclusions

The agricultural environment has its main influence on floor surfaces inside farm buildings. The floor surfaces are exposed to a chemical and physical environment, which is very aggressive, because of different elements originating from manure, drinking water and feed stuff.

Floors and other building components of farm buildings show different degrees of degradation. Concrete material, which is often used in floors and walls need a high material quality to resist against the chemical and physical attacks.

6 References

1. CIGR (1989) Climatization of Animal Houses. Faculty of Agricultural Sciences. Gent State University. CIGR-report, 119 p.
2. Boxberger, J., Eichhorn, H. & Seufert, H. (1988). Manure: Handling, Storage, Spreading (in german). Betongverlag. Dusseldorf.
3. PV. (1989) Rules for the Climate in Pig Houses (in dutch with summary in english). Report P. 1.43, Proefstation voor de Varkenshouderij (PV), Rosmalen.
4. Martensson, L. (199 1). Chemical and Physical Environment in Farm Buildings (in Swedish). Department of Farm Buildings. Swedish University of Agricultural Sciences. Special Report 187. Lund.
5. Hoeksma, P. (1988) The Composition of Slurry marketed to Arable Farms (in dutch with summary in english). IMAG-DLO. Wageningen.
6. O'Donnell, C., Dodd, V.A., O'Kiely, P. & Richardson, M. (1995) A Study of the Effects of Silage Effluents on Concrete: Part 1, Significance of Concrete Characteristics. ***Journal of Agricultural Engineering Research*** Vol. 60, pp 83-92.
7. Sangarapillai, V.G. & Dumelow, J. (1993) Rapid Assessment of the Durability of Concrete exposed to Silage Effluent. *Farm Building* ***Progress, No.*** 114, pp. 15-17.
8. Kramer, W. A. & Braam, C. R. (1997) Deterioration of Concrete Exposed to Lactic and Acetic Acid. Proceedings of the International Symposium on Concrete for a Sustainable Agriculture. 2 l-24 May 1997. S tavanger.
9. Swierstra, D. & van den Elzen, M. J.M. (Eds) (1993) Floors for Outdoor Horticulture. Technical Requirments and Design Alternatives. (in duch with summary in english). Report 93-16. IMAG-DLO. Wageningen.
10. Baxter, S. (1984) Intensive Pig Production. ***Environmental Management Design*** Granada Publishing. London
11. Daelemans, J. & Almay, F. (1993) Standardization of Precast Slatted Floors for Animal Houses. Proceedings of the International Symposium on Concrete for a Sustainable Agriculture. 21-23 April 1993. Bologna.
12. CEN (1996) Precast Concrete Floors for Livestock. Draft proposal - version 11. CEN/TC 229/WG2/TG2.
13. Svennerstedt, B. (199 1) Concrete in Agriculture (in Swedish). Department of Farm Buildings. Swedish University of Agricultural Sciences. Report 73. Lund.
14. De Belie, N. (1997) A Survey on Concrete Floors in Pig Houses and their Degradation. ***Journal of Agricultural Engineering Research*** Vol. 66 (3), pp 15 1-156.
15. Kleinlogel, A. (1960) Influences on Concrete of Different Physical and Chemical Elements (in french) Dunod. Paris.
16. Dumelow, J. & Owen, J. (1996) Skid Resistant Floors for Pigs. *Rural* ***Design and Building Journal.***
17. Bergschöld, B. & Jansson, I. (1983) Comparing Tests of Corrosion Protection in animal Houses (in Swedish). Department of Farm Buildings. Swedish University of Agricultural Sciences. Special Report 132. Lund.
18. Eistrat, K. & Thore'n, A. (1980) Microbiological Corrosion - A Literature Review (in Swedish). Swedish Corrosion Institute. Report 1980:9. Stockholm.
19. Dolby, et al (1988) Rural Constructions in Timber-handbook. Department of Farm Buildings. Swedish University of Agricultural Sciences. Lund.

Upgrading the use of recycled aggregates

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Abstract
Use of crushed concrete and masonry in the UK is mainly for lower grade applications and its resource potential (as measured by its position in the marketplace) is frequently undervalued. In recent years there have been moves to demonstrate its wider potential eg in ready-mixed concrete for the new Environmental Building at BRE. This paper describes progress in collaborative programmes with UK industry to improve guarantees of quality for use in concrete blocks, precast concrete, and by the introduction of a pilot scheme for quality control. This paper also introduces new work to improve the availability of information and in particular the establishment of an internet-based materials information exchange. This is designed to be attractive by being simple, quick and self-maintaining.

Concrete blocks were made with up to 75% recycled aggregate on a full-scale industrial plant and tested in beam-and-block test floors. All performance indicators were exceeded by a very wide margin. With regard to precast concrete, no effective difference was found in initial tests with the replacement of up to 20% of coarse aggregate or 10% of fine aggregate with reclaimed product. Quality control of recycled aggregates for these construction products should not need to be very onerous - with floor infill blocks because of the massive safety margin, and with reclaimed product in precast because this is already a much better controlled source than demolition waste. The prospect for some utilisation of fine recycled aggregates in higher-grade applications is considered possible both in the precast application and for cement manufacture.
Keywords: cement, concrete blocks, demolition, flooring, internet, precast, quality control, readymix, recycled aggregates

1 Introduction

Worldwide demand for aggregates is on an increasing trend and long-term projections indicate that the UK is no exception. As in the UK, there is an increasing commitment to the principles of sustainable development, with an emphasis on the need to make greater use of waste and recycled materials and use primary aggregates more efficiently. Although waste and recycled materials already account for about 10% of the aggregates used in the UK, there is a considerable potential to increase this level of usage and it is UK Government policy to promote this where this furthers aims of materials conservation and environmental protection.

Many countries, including the UK, already have a substantial use of recycled aggregates in road construction, where fairly large quantities of low-specification aggregates have traditionally been required. While attempts are being made to increase this usage in the UK, it must also be borne in mind that the construction of new roads on virgin land is not a sustainable activity and that already this is losing its importance with respect to road maintenance and the construction of high-speed rail networks and urban transit systems. All of these activities generally require a greater proportion of materials produced to higher specifications. It is against this background, and the decreasing availability/increasing cost of landfill, that efforts have been made towards putting in place higher-grade outlets for recycled aggregates.

2 Specifications for recycled aggregates

European standards for all types of construction aggregates are currently being prepared and are intended to include the use of recycled aggregates, provided, of course, that they meet performance requirements for the intended end-use. An ad hoc group of the relevant Technical Committee (TC 154) has prepared a technical report on the specification of recycled aggregates from which specification clauses will be drafted for inclusion in the product standards. Unfortunately this will not be ready in time for the projected implementation date (the year 2000) for the first package of aggregates standards. Thus implementation of European (CEN) specification requirements for recycled aggregates may have to wait for the first revision of these standards, or at least until amendments are issued.

Specifications for recycled aggregates in concrete prepared in the Technical Report of the ad hoc group for recycled aggregates are based on the RILEM Recommendation [1]. Additional recommendations made by the ad hoc group include additional quality control procedures - rates of testing, and very importantly, the input control of materials entering recycling plants.

3 Recycled aggregates in ready-mixed concrete

The RILEM Recommendation was used as a basis for the specification of recycled aggregates in ready-mixed concrete in BRE's new Environmental Building [2] and in the construction of a strong floor facility at BRE's Cardington Laboratory [3]. The use of this specification in conjunction with the British Standard for concrete (BS5328) had already been explored as a permissible within the UK Building Regulations as part of a study carried out by BRE for UK Government Minerals Planning [4]. Quality control procedures relating mainly to input control and frequency of testing were put in place for each of these projects.

A new project to assist a more general application of recycled aggregate in ready-mixed concrete has been started at BRE. This involves partnerships of demolition firms, recycling plants, readymix companies and clients. The clients in the first instance will be Local Authorities in which there are various pressures to promote recycling - these are applied by Central Government and relate to permissions for mineral extraction and the provision of landfill space. Naturally, Authorities in urban areas, particularly in SE England are under the greatest pressure. The aim of the project is to put in place quality control procedures to allow a more general use of recycled aggregates in higher grade applications. This may not just be for structural concrete, but could also be used, for example, for cement-bound sub-base materials in roads - a use which was introduced in the Highways Specification in 1991 [5], but not, as far as it is known, taken up.

It is intended that the quality control procedures will be backed up by a BRE Digest to be published in 1998. This Digest will bridge the gap between specifications as drafted for CEN and current UK practice.

4 Recycled aggregates in manufactured products

In the BRE study on specifications [4] another route for the application of recycled aggregates was identified and this is potentially simpler to implement. Manufactured products should be guaranteed by the manufacturer as fit for purpose. Thus, in principle, the quality control of any input of recycled material needs to be verified only by the manufacturer of the product. In practice, however, not all products are specified purely on performance and standards often contain both recipes and performance requirements. In these circumstances, proof may be required to the satisfaction of the user that a recipe can be varied without detriment to the product.

4.1 Concrete blocks

Another partnership project led by BRE has concentrated on the use of demolition waste in precast concrete blocks. The intended use for these blocks was for beam-and-block flooring systems. This was considered to be a fairly non-onerous end-use since there are no weathering requirements and the general experience with loading tests on floor is that the margins of safety are very large (at least a factor of 10).

Initial studies in this project were concerned with the requirements for recycled aggregates to be used in conventional blockrnaking plant. These plants rely on the free fall of materials in hoppers etc and thus a sufficient proportion of fines must be removed from the recycled aggregate to ensure that clogging of the plant does not occur. The grading of the recycled aggregates thus needs to be coarser than that needed to produce dense, well-compacted blocks. Some natural sand needed to be added to the recycled aggregate at the mixer ie it was not possible to produce good blocks containing 100% recycled aggregate with conventional plant. Blocks with up to 75% recycled aggregate could be made with no difficulty. (ARC Conbloc using materials supplied from Pinden

Plant & Processing). Floor loading tests were carried out by Kingsway Technology on blocks from 3 trial runs containing between 50% and 75% recycled aggregates. Beam-and block floors 2.9 x 3 metres were constructed for each trial run and finished with a 50mm thick 3:1 sand:cement screed which was left to cure for 28 days. Each floor required the use of 6 beams and 70 blocks. Floors were loaded centrally via a 100mm square plate. Results for ultimate load gave safety factors of between 33.7 and 39.0, and deflection was well within limits given in BS8 110 for the structural use of concrete.

4.2 Precast structural concrete

A further partnership project led by BRE in association with members of the Precast Flooring Federation, Leeds, Nottingham Trent and Sheffield Universities is concerned with the recycling of rejected precast elements within precast works. Wastage of concrete within precast works due to a number of factors such as breakage, poor compaction, malformation and off-cuts can sometimes approach 10%. Although some materials have been crushed and used as hardcore rather than landfilled, there would be further advantages if the material could be fed back into the production line. Use of reclaimed product in precast is already practised in some countries where this is allowed in the specifications. The challenge in the UK where current specifications preclude its use is to produce an industry code of practice/industrial standard that will be acceptable within the construction industry as a whole.

Trials are being carried out at 4 precast works, and initial tests on various levels of replacement should be complete early in 1998. Initial results indicate that there is little if any effect from the replacement of 20% of the coarse aggregate and 10% of the fine aggregate by reclaimed product. Reclaimed product is a purer and more consistent material than recycled aggregates from demolition waste and thus requirements for quality control are very much reduced. The incorporation of a small percentage of fine material without detriment also illustrates the purer nature of reclaimed product - most research workers have found the fine material from demolition waste to be too contaminated for very successful use in concrete.

When the use of reclaimed product in precast works is well established as routine within the construction industry, it may be possible to consider an extension to this practice. If buildings were "deconstructed" rather than "demolished" then precast elements could be retrieved and returned to the manufacturer for recycling.

4.3 Cement manufacture

Demolition materials can form a source of raw materials for the preparation of raw feed to cement kilns producing Portland cement. This forms part of a Brite-Euram project "Construction recycling technologies for high quality cement and concrete" led by the Spanish cement company Lemona of Bilbao with Labein also of Bilbao. BRE is part of the consortium which also includes work on concrete technology by Holzmann, Prüftechnik and BAM of Germany and Taywood Engineering (UK). It is hoped that cement manufacture will be able to cope with the higher level of pollutant found in the fines derived from crushed demolition material, and thus, together with the use of recycled aggregate in concrete, offer the potential of high grade applications for all size fractions.

5 Materials Information Exchange

One of the key restraining factors which prevents the more effective use of demolition materials and surplus construction materials is lack of timely information on arisings and information regarding potential construction projects or production processes where such waste could be utilised. A potential user of waste needs to know what waste is becoming available and when (or for how long), in what quantity, where, and what cost. Conversely, a producer of waste, whether construction, demolition or at a materials production site will ask similar questions in relation to potential disposal routes. Timely notification of material availability and future sources will facilitate advance planning and greater take-up of material.

In response to these requirements BRE, with support from the UK Department of the Environment, Transport and the Regions have developed an intemet-based Materials Information Exchange. This consists of four parts:

- A 'board' showing materials for free collection or sale, with text and menu boxes for nature of arising, quantity, location, cost and timing
- A category of unutilised materials, for example, over-ordered stock available
- A 'Materials Wanted' board with text and menu options similar to above
- An 'up and coming' demolition board to notify potential users of future sources.

The system is available to any operator who has an internet connection. In operation the exchange is not complex and relies on a series of predesignated 'click' boxes giving options relating to most of the details required. The operator generally only needs to input contact point of the supplier or user. The system will automatically search all input data to match the search commands. The time for both inputting and extraction of information is measured in seconds rather than minutes. Furnished with the contact information, the operator is then free to negotiate for the use of the material.

The Materials Information Exchange is designed to be self-maintaining and users are free to enter or extract information directly from the system without the need to contact a third party. The self-maintaining nature of this system means that there are no subscriptions or user fees. It is considered that the simplicity, speed and cost-free nature of the system will provide an attractive package to the industry and ensure take-up and use of the system. The address of the system on the internet is:

http://helios.bre.co.uk/waste

BRE are about to commence an integrated awareness, consultation and review exercise with potential users, industry trade associations, Local Authorities etc., targeted initially on London and SE England. This aims to encourage take-up of the scheme and, in the light of consultation, to identify improvements that will increase the effectiveness of the exchange.

6 Future developments

BRE, Construction Directorate of the UK Department of the Environment, Transport and the Regions, the UK Environment Agency and Hertfordshire County Council intend to establish a Sustainable Building Network aimed primarily at Local Government which has a crucial role to play in developing and implementing ways of promoting sustainable practice in industry on a local and regional basis. They act as clients in specifying construction projects, as influencers through environmental fora such as Local Agenda 21 and as enforcers in planning and building control.

As well as providing information on current best practice, and facilitating the building of partnerships to achieve these aims, it is intended that the Network will provide a positive feedback of new ideas and experience eg Hertfordshire County Council anticipate undertaking a study of reuse and recycling of materials in the construction of schools and are willing to share their information through the forum.

7 Acknowledgement

This work forms part of the Environment Research Programme of the UK Department of the Environment, Transport and the Regions.

References

1. RILEM TC 121-DRG (1994) Specifications for concrete with recycled aggregates. ***Materials and Structures,*** Vo1.27, pp.557-559.
2. Collins, R.J. (1997) Reuse and Recycling in Construction: BRE Case Studies, in Buildings and the Environment, CIB Task Group 8, 2nd International Conference, Paris, 9-12 June, 1997, Vol. 1, pp.627-34.
3. Collins, R.J. (1996) Recycled Aggregates in Ready-Mixed Concrete, in ***Sustainable Use of Materials***. BRE/RILEM international seminar, Watford, 23-24 Sept 1996.
4. ***Collins,*** R.J. and Sherwood, P. (1995) ***The Use of Waste and Recycled Materials us Aggregates: Standards and Specifications. HMSO,*** London, 60pp.
5. Department of Transport, Scottish Office, Welsh Office and the Department of the Environment for Northern Ireland (1991) Manual of Contract Documents for Highway Works, Volume 1 ***Specification for Highway Works,*** HMSO, London.

Changeable Internal Surfaces for Seasonal Flexibility

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Abstract
Even in the North of Scotland, there are times of the year when heat reflection or retention are no longer the principal properties required from interior building surfaces to achieve thermal comfort for its occupants with minimum energy consumption . As a structure passes through its thermal balance point after the winter months it would be better served by internal surfaces which admit rather than resist heat . This paper considers the practical implications of employing materials or systems that change with the seasons to reflect the external climate .

The widespread use of plaster and plasterboard satisfies the need for a material which provides a rapid response to heating systems used intermittently to match the demands of a fragmented pattern of occupation . If cooling systems are employed in the summer , the ability to respond quickly may also be an asset . As passive and or night-time cooling becomes more widespread ; these conventional lining materials become less appropriate outside the heating season .

Aside from the energy gains to be anticipated from such surfaces , there is the added value to be derived from greater flexibility in future interior arrangements and enhanced sensory stimulus as surfaces change with the seasons . If the right surface finish is chosen , passive humidity control is also possible . The performance of these surfaces is modelled with standard thermal analysis software .

The particular material considered is the traditional Tapestry , which is a well established art form and still well perceived in contemporary society . Experiments with suitable fabric have shown that in transient conditions the thermal properties are a match for foil backed plaster. The use of wall hangings as functional art with a long life expectancy is explored and the benefits of the reintroduction of this portable surface are explained .

For ease of interpretation this article will concentrate on offices which are probably the category of building most likely to benefit from the ideas being promoted. Quantitative analysis in the form of energy consumption and life cycle analysis is presented to gauge the magnitude of the benefit to be anticipated from these variable surfaces .
Keywords: Thermal Admittance, tapestries, sustainable surface finishes.

1 Introduction

A number of recent buildings have used enhanced thermal mass of internal partitions to enable passive cooling to be achieved . A good example of this is the new Scottish Office building in Leith Docks, Edinburgh. Here an inner leaf of precast concrete has paint applied directly to the concrete . This gives a much higher thermal admittance value than would a more conventional finish . For an office where cooling represents a significant part of the annual energy budget this is a reasonable strategy. The ability of the structure to come up to temperature on a cold Monday morning, however, will be compromised by this choice of material. The Scottish Office building was heralded as a testing ground for green principles when it was the subject of a review in the Architects' Journal [1] yet on a cold dark day the prospect of contemplating slabs of painted concrete may not provide much inspiration or warmth for the occupants. The belief that the addition of mass to a building will reduce its energy requirement is now widespread ; according to another recent article which cites the example of a typical naturally ventilated office with 100% double glazing and internal gains of 35 W/m^2, thermal balance at zero energy is anticipated to occur at an external temperature of 0°C [2]. This level of information is not, however, new and has been available in a BRE Report for some time [3]. This report felt able to predict the effects of mass in promoting natural ventilation in what seems to be a very palatable form but few people seem to have been using it .

The ability of a surface to absorb heat is essentially a skin effect and so only a relatively small volume of material is required to influence interiors . Very often the actual interior surface used changes on an all too regular basis as owners and occupants follow trends in interior design or as the occupants themselves change . It is not always fully appreciated that even a fairly thin coat of new material to an internal surface can influence the behaviour of the room it encloses. If this is recognised and interiors are designed to allow flexibility with season and type of use then tangible benefits should ensue. People exchange heat with their surroundings predominantly through convection and radiation from the clothing that they chose to wear. The experience of thermal comfort is usually described by the Dry Resultant Temperature of the room which is a combination of air and surface temperatures . People are much more likely to appreciate the conditions in a space if they are exchanging heat as radiation rather than convection from systems which move air . In domestic construction attempts to use hot air systems have not been well received in the UK and a straw poll of owners of such systems would probably show that a significant number of these systems have been abandoned , yet in offices they are the norm. Creating environments which allow surface temperatures to become much lower than the air which they enclose is not likely to be well received. As people spend more time in environments with forced air movement (car , plane and office) are they experiencing the best conditions that can be achieved? If heating or cooling is to come from surfaces rather than air then those surfaces must be kept at the correct relative temperature so that in winter too much mass is not readily available to require there to be warm air supplied at too high a temperature for optimum comfort .

2 History

Before the widespread use of plaster as a surface finish it was common to use textile hangings as a decorative feature . As well as providing decoration , these hangings would provide insulation and more importantly allow the rooms to heat up much more rapidly than would be the case with exposed stone or brickwork . The use of a thin covering which is disinclined to absorb heat over a massive material which is able to dissipate heat enables the heating or cooling phases of interiors to take place as quickly as possible . This reduces the period of use and creates a more reactive system . Timber lining could also be used to provide an enhanced warm up mechanism but is not demountable to the same degree . Cost was of course a major factor and so for those who could not afford to commission a tapestry , less elegant and more unsavoury linings were often chosen using material readily available from the fields or recycled materials such as newspapers in the place of wall paper; today such practice would be questionable yet the thermal properties of these surfaces may well have made them a good choice . There is now evidence of some excellent Scottish tapestries which no doubt enriched the lives of those who were able to see them as well as providing the low admittance to be welcomed on a cold Scottish morning. Although these tapestries were expensive and perhaps a status symbol they were ‘long lasting and portable . Tapestries such as those uncovered at Traquair House, Scotland were widely used in the great houses of the 16th and 17th Century . These would have supported local textile artists at this time . Wall hangings are still relatively widely available today although many feature reproductions of scenes from this golden age .Less frequently contemporary artists have been commissioned to create corporate images to hang in company offices or meeting rooms . Examples of works commissioned for a particular position in a particular building are quite rare in the last few decades , one such example is the Aberdeen Art Gallery Tapestry [4] which was designed to reflect light according to time and season .

3 Internal Surfaces

3.1 Thermal Properties

The ability to be able to lower surface temperatures in the summer and raise them in the winter allows a building to reduce the convective heating and cooling requirements and so reduce energy consumption for internal climate control . Such a system combines the benefits to be experienced in a timber structure when in heating mode with those of a massive stone church during the cooling season . Even a temperature rise of a half or one degree which is to be expected from a wall hanging in a lightweight structure is worth the effort of attaching it to the walls . For heavyweight surfaces the gains are greater and if a low emissivity material is attached to the rear face of the hanging then another degree or even two is possible .

The use of wall hangings in winter allows for them to be removed in summer and if the wall behind is of heavyweight structure it is possible to provide cooling during this period with thermal mass . For this to work it is important to be able to demonstrate that the wall hanging is able to match the thermal properties of plasterboard which it could replace where seasonal flexibility is required .

A simple experiment was devised to measure the relative performance of internal surfaces when subjected to gentle winter heating . The results of warming four surfaces against a cold medium grade concrete block wall are shown as Figure 1.

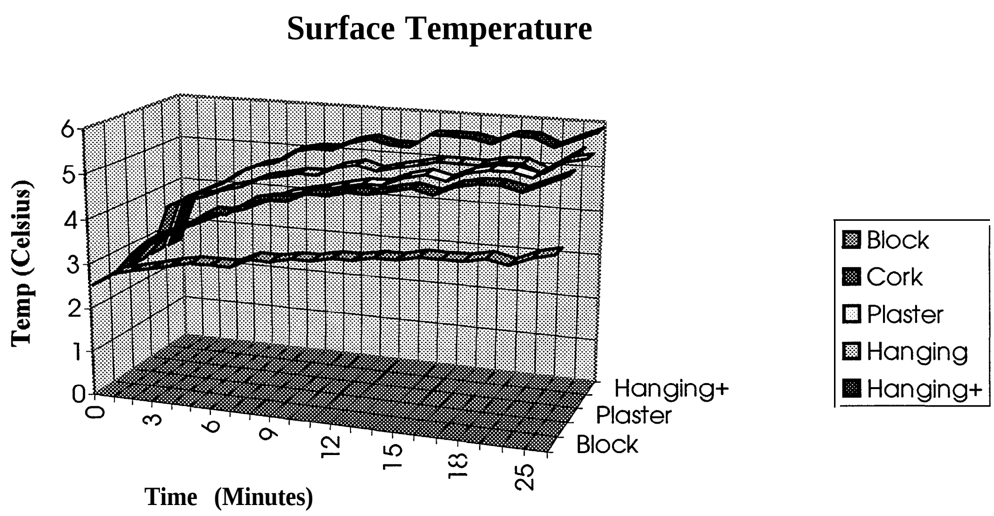

Figure 1

It can be seen from these results that lining the blockwork with cork , plaster , hanging and hanging with a foil backing gives increasing ability to raise the surface temperature of a room and so increase the radiant element of thermal comfort for occupants of that room under heating mode These properties are similar to those found for plasterboard and polyurethane in pioneering work on admittance in the 1970s [5].

3.2 Energy Saving

The admittance of a concrete block wall can be seen to fall from 6.0 to 3.0 W/m^2 °C when covered with a tapestry of modest thickness which is similar to the effect found when stone walls are timber lined . It is easy to demonstrate the gains of such a strategy with the computer simulation software widely available these days , rather than make extravagant claims by choosing an office with very high casual gains such as the 35 W/m’ it is better to claim 10 to 20% using an example which has had many of the casual gains removed from it by adroit design .The potential of variable admittance can be demonstrated to achieve a 20% reduction in the annual energy requirements for a two storey office of 360 m^2 [6] by reducing heating loads without increasing cooling , humidification or dehumidification requirements but further work is in hand by the Author to provide data on the thermal and moisture properties of surfaces which might be used in this way . The building used in the simulation was a cellular office with concrete block partitions and the hangings were applied to these partitions only to reduce cost and condensation risks .

Thermal energy loads are shown for the exemplar building , Figure 2 , to demonstrate the improved performance when the wall hanging is used compared to the exposed concrete block. In this simulation the hanging was removed for the months of June to October.

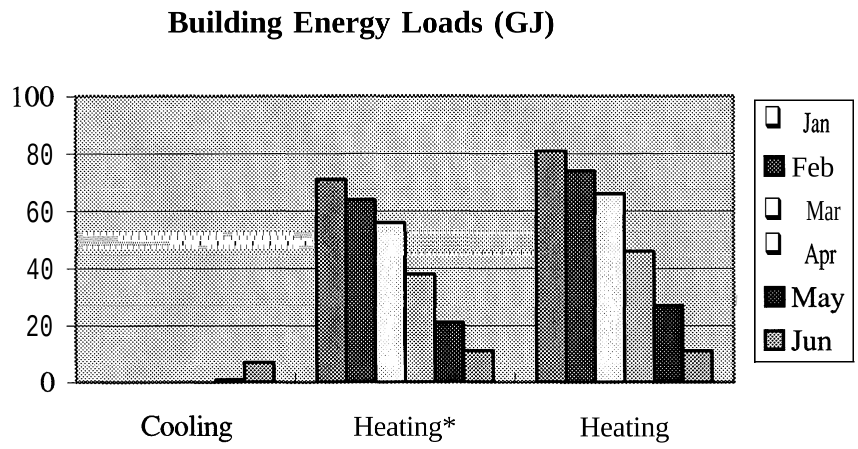

Figure 2

The experiments of Figure 1 , modelled in Figure 2 used a Cotton Hanging but similar performance might be expected from Wool or Jute fibres .

3.3 Humidity Health and Fire Issues

The question of where to put the variable admittance surface should be mentioned . Whilst it is reasonable to use the floor for this purpose there are health issues associated with floor coverings regarding dander shed by people and other nutrient sources which might encourage colonies of dust mite to take up residence . Walls are a much safer option and depending on the internal arrangements may provide a greater surface area . The other improvement that natural fibre hangings in particular can achieve is humidity control . When rejecting air conditioning a project team will also reject the opportunity to control humidity . Fortunately in the higher latitudes this is less of a problem but the dangers of high or low humidities are still being discovered so it is as well to keep within the range 40 - 60% . Whether this is achievable depends on the activities within the building and the ability of the surfaces to act as a buffer for transient conditions . Once more the painted concrete wall is not ideal for this purpose. Wool fibres for example which can hold 16% of their weight within the fibre structure (that is bound up in the structure and not available to other organisms), they have the potential to dry air from 0.02 kg/kg to 0.002 kg/kg moisture content and under the right temperature regime this could achieve a change from 80% to 20 % Relative Humidity [7].Any material attached to walls must not provide a substantial fire load , Wool for example is able to suppress ignition ; further tests of performance in fire are being conducted by the Author’s host institution.

4 costs

The use of a basic solid wall with only a simple paint finish can bring the costs of a project down , yet the use of a tapestry which may be a bespoke item will more than remove this saving . The additional cost for new construction may be taken as simply the difference between that of plasterboard (1.5 ECU / m^2) and a mass produced jute wall hanging (34 ECU / m^2). Taking into account future refurbishment , total cost may not be all that much higher than for a conventional set of materials . If the energy saving per year (80 GJ) is set against the cost of the extra materials (240 m^2) using a price for energy of 20 ECU/GJ the simple payback period is 4.9 years . There are now a number of lower cost mass produced rugs which are available at reasonable prices if a short term fiscal view is to be taken . It would appear that the changes proposed might be at no additional cost or at worst fiscally neutral . It is for clients and users to decide on the advantages in terms of sustainability and embodied energy .

5 The Contemporary Paradigm

Not everyone wishes to employ traditional solutions to modern problems . There are opportunities to develop technical solutions more clearly identified with the twenty-first century . It would be possible to create surfaces which were of low admittance but consisted of an open porous structure which could be closed when the weather became cooler. If this were to be fixed to the surface of a massive substrate then the flexibility already demonstrated with hangings which require to be removed or rolled up , could be reproduced at the flick of a switch .

In recent years there have been few significant developments in interior finishes and the trend towards massive construction for cooling may provide the necessary stimulus to the Building Products Industry to enrich the range of materials on offer. The development of textile materials with aluminium foil backing might also have wider commercial potential.

6 Value added

The provision of a basic structure which is finished by occupants allows greater ownership of the interior space thus created. For companies wishing to promote corporate identity this may be attractive so long as this identity has some reasonable life in the marketplace . The desire to promote and commission cultural art which is also functional should add weight to this concept , be attractive and add value to the building .As an organisation grows and moves on to new premises there is then the opportunity to take familiar elements of the old workplace to the new building . The building itself may be the creation of an international style of office but local culture can be reflected in wall hangings as it has for centuries and in doing so satisfy the principles of Agenda 21 and Agenda 2000 [8].

7 Conclusions

The use of natural ventilation assisted by massive elements within the construction of offices is to be commended . As with any new ideas there will be successes and lessons to be learned . By paying due regard to all seasons in the design of low energy offices further performance gains can be achieved .The use of higher specification interiors which might be expected to have a longer life and thereby a lower total cost risks should be reduced and flexibility retained . The latest breed of low energy offices may have their problems but the shift towards greater occupant control should be able to enable the users themselves to overcome these .

References

1. Edwards , B. (1993) Civic Architecture with energy concerns on its agenda *The Architects' Journal September* 1996
2. Cousins , F. and Laing , R..,(1996).Thermal Mass. *Heating and Air Conditioning October 1996.*
3. Pethbridge , P., Milbank ,N.O., Harrington-Lynn ,J. ,(1988). Environmental Design Manual , *BRE Report, Department of the Environment.*
4. Brennan , A. (1965) The Aberdeen City Tapestry . Aberdeen Art Gallery , Scotland.
5. Bloomfield , D.P. (1975) The effect of intermittent heating on surface temperature in rooms. *Building Science* , Vol. 10, pp. 11 l-l 25.
6. Hevacomp Ltd., (1990) . K2 Thermal analysis software.
7. Martin , P. J. ((1991) Criteria for Selection of Soft Furnishings for Healthy Buildings. *IAQ 91 Healthy Buildings.* pp. 210-214.
8. Earth Summit (1993), Agenda 2 1 UN Programme for Action. *United Nations.* London.

The Problems of Phosphogypsum Utilization in Lithuania

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Abstract

There are no mines in Lithuania but there are fertilizer waste dumps. For many years phosphor fertilizer has been made in Kedainiai chemical plant in the central part of Lithuania using apatite as a raw material which is brought from Kola peninsula. During the production of **1** t of phosphoric acid 4,5 t of phosphogypsum is produced. For many yers phosphogypsum has been transported into the dump in which more than 8 mln tones of phosphogypsum have been accumulated. Phosphogypsum includes volatile fluor and phosphoric acid. Ecological polution of the waste materials is obvious, however, according to Lithuaniain laws the plant does not pay any fee for the damage.

Institute of Architecture and Construction has prepared several technologies concerning the utilisation and remaking of the phosphogypsum wastes into building materials and products. The report is based on the problems of their characteristics and realization.

Keywords: Lithuania, phosphogypsum, utilization, waste.

Introduction

Lithuania lacks sources of natural gypsum. That's why Latvian natural gypsum from Seurieše pit was used in the production of gypsum products. This pit has been exploited for a very long period of time in spite of comparatively low quality of gypsum.

However, in Lithuania we have large amounts of fertilizer production waste. For many years phosphorus fertilizers have been produced by Kedainiai chemical plant (today joint stock comp. "Lifosa") which is in the central part of Lithuania. The main raw material used is apatite brought from Russia, Kola Peninsula.

With the production of one ton of phosphorus acid there form 4.5 ton waste material, i.e. phosphogypsum. For many years phosphogypsum has been transported into the so-called waste-hills in which more than 8 mln. tons have been accumulated.

Phosphogypsum includes volatile fluor, the remainders of phosphorus acid and other harmful materials. The pollution of the environment is obvious enough, but still, according to the present laws of Lithuanian Republic, the enterprise does not pay any fees. The Institute of Architecture and Construction has prepared some technologies concerning the utilization of these waste materials and the processing of phosphogypsum into building materials and products.

Technology of the utilization

Already in 1987 in Kedainiai near the chemical enterprise a plant for phosphogypsum processing into P-modification building gypsum was built according to the project made by the institute. The wasteless technology was based on the neutralization of phosphogypsum but not its washing with water.

The essence of the technology is as follows:

- phosphogypsum dehydrate in which there is no more than 1.3% of general P_2O_5 and 0.9% P_2O_5 which is water soluble is neutralized with lime cream and the pulp is filtered;
- filtrate is once again used for lime cream preparation;
- filtered phosphogypsum is dried;
- dried phosphogypsum is dehydrated;
- the product is cooled down;
- the product is ground;
- the product is stored and stabilized.

This technology of β-semihydrate gypsum production is distinguished itself by many advantages: there were no technological flowing waters, the process was continuous, and the product produced distinguished itself by stable properties: the beginning of binding – 13-15 min., the end – 20-24 min., strength under pressure after 2 h is 5-6 MPa, strength under pressure of dried products 12-13 MPa. Gypsum slabs, blocks, mixtures for finishing works have started to be produced of this building gypsum in Lithuania.

In 1990 with the restoration of Independence in Lithuania the economical situation changed. The amount of production diminished and the size of building material industry decreased about 80%. The phosphogypsum processing plant did not manage to adjust to new conditions and in 1993-94 β-phosphogypsum plant was finally closed. At present this product is no longer produced in Lithuania.

From 1997 the joint stock company "Lifosa" changed the technology of fertilizer production, and the waste material is no longer dehydrate phosphogypsum but semihydrate acid phosphogypsum. A very small amount of it the plant processes into a high-quality a-modification building gypsum. The main properties of this gypsum are:

- the beginning of binding – 16 min., the end – 32 min., strength under pressure after 2 h – 14.4 MPa;
- P_2O_5 general – 0.33%, P_2O_5 water soluble – 0%;
- fluor general – 0.25%, fluor water soluble – 0%.

However, today the amount of the production does not meet even the minimal demand of producers and consumers.

In 1997 the firm "Palemono keramika" using the technology invented by the Institute of Architecture and Construction produced the first experimental batch of a new building material – anhydrite cement. The raw material for this binding material – i.e. dehydrate acid phosphogypsum – has been taken from that part of phosphogypsum waste-hills where new waste materials were not transported in last years. The upper and the middle parts of the hills (2/3 of the height) have been thoroughly examined. The chemical tests showed that during many years rain and other natural factors considerably diminished the amount of harmful admixtures in the phosphogypsum – dehydrate waste. The average chemical compositions was as follows: R_2O_3 – 2.03%; CaO – 31.63%; SO_3 – 44.82%; F general – 0.2%; F water soluble – 0.04%; pH – 2.6-4.8%;

The essence of anhydrite cement production technology is the following: acid phosphogypsum – dehydrate is neutralized by lime cream in clay mixer, then clay and glass slime (the waste got during TV screen grinding) additives are introduced and the produced mixed material is burned in gyrator furnace. The approximate composition of materials is: 79.0-79.3% phosphogypsum; 16% clay; 4% glass slime; 0.5-1% lime. The production was carried out in a claydite shop of a plant "Liapor". Anhydrite cement was burned at 850-900°C and the product produced in granulated shape. The chemical composition of the granulate is: SO_3 – 36.45-41.05%; CaO – 32,0-33,27%, R_2O_3 9,35-15,6%, P_2O_5 water-soluble – 0.03%; F general – 0.03-0.06%; F water soluble – 0%. The mechanical strength of the granules 1.5-2.0 MPa; volume mass 967-985 kg/m^3.

In the next stage the granulate is ground and then we get anhydrite cement. The main physical-mechanical properties are these: the beginning of binding 1 h 20 min., the end – 2 h 15 min., the strength after 28 days under pressure is 20-30 MPa, under bending – 3-4.5 MPa.

This binding material can successfully replace the ordinary portlandcement in many building spheres. It should be also profitable from the economical point of view as anhydrite cement is burned at much lower temperature than portlandcement. Yet, its production size is still small.

Conclusions

In Lithuania, as well as in the former SU, gypsum materials and products took an insignificant place in the nomenclature of building materials. Because of extremely low prices of energetic resource cement was used nearly in all spheres.

With the change of both political and economic situation building materials made of gypsum have been widely used, especially for interior trim. In fact all these materials are being imported.

However, the amount of local phosphogypsum waste with the realization of technologies suggested by the Institute of Architecture and Construction, could ensure a long-term production of gypsum materials. At the same time, it would give the possibility of the gradual diminishing of accumulated phosphogypsum waste dumps.

Repair of environmental constructions with the high-performance concrete SIFCON

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Abstract
SIFCON (Slurry Infiltrated Fibre Concrete) is a High-Performance Concrete, which provides a high ductility due to a steel-fibre content of about 10 % by vol. In addition, an extremely dense microstructure is characteristic of SIFCON. With this material, existing structures handling with water contaminating fluids can be repaired so that they can fulfill the adequate environmental requirements. The high fibre content of SIFCON requires a special method of production: in a fibre bed, which is first spread onto the existing structure before, a high performance mortar is infiltrated. Due to the high fibre content, SIFCON shows a high resistance to impact and abrasion as well as a favourable control of crack widths. Therefore structures, which suffer abrasion and impact, can be improved by SIFCON.

SIFCON as a ductile layer of high performance fibre concrete with an extremely high amount of fibres can be used also to minimize wear and tear. However, SIFCON does not perform any load bearing function, because it is applied only in relative thin layers.

Further applications could be the improvement of airport runways, concrete pavements, parking floors, sewage plants etc..

Until now the fibres for SIFCON surfaces have been spread by hand. To improve the efficiency mechanical procedures are necessary. Suitable instruments - for small areas as well as for large and long lanes - are being developed at the present time.

Keywords
covering layer,
environmental constructions,
high-performance steel fibre concrete, ductility, high strength,
impact, abrasion.

1 Introduction

Structures dealing with water-contaminating substances must guarantee the protection of soils and ground- water. The. political framework for such buildings in Germany is constituted in the water protection law (WHG) which states:

"Installations for storing, filling, producing and handling of water-contaminating substances . . . have to be built in such a way that the contamination of the environment, especially ground water, is prevented".

Considering this law (WHG) many existing installations, in which water-contaminating substances are stored, filled or handled, have to be repaired and sealed subsequently. Typical examples are gasoline stations, fuel depots and chemical industry plants. If the existing structure is still on able to fulfill the loadbearing function, i.e. it has not to be totally rebuilt, a subsequent application of a sealing layer can satisfy the appropriate regulations. For such sealing layers often polyurethane resins (PUR) or steel are used. However, layers of high-performance steel fibre concrete (SIFCON) have been used in Germany recently and are a significant and efficient alternative for such secondary barriers.

2 SIFCON

SIFCON is the short term for "Slurry Infiltrated Fibre Concrete". This cement-bound fibre material was developed in the USA almost 15 years before and was successfully used in several buildings [1,2]. SIFCON is a fibre concrete with an extremely high steel fibre content of about 10% by vol., corresponding to nearly 800 kg/m^3.

The high steel fibre content improves the ductility of the usually somewhat brittle material like concrete and cement mortar to several orders of magnitude nearly as strong as steel [3]. At the same time an optimal crack distribution is obtained. The typical crack width is limited to ranges of O.Olmm to 0.03mm.

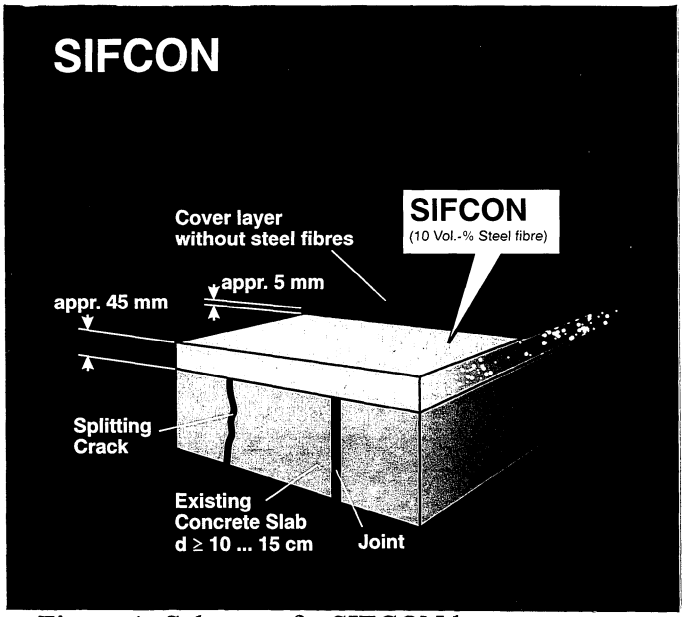

Figure 1: Scheme of a SIFCON layer

The special mixture of the infiltrating mortar ensures a very dense microstructure. Both components, steel fibres and mortar, guarantee a high-quality cement-bound material. Due to the high ductility SIFCON can be applied without any joints over large areas (Figure 1). In addition to alternative sealing layers SIFCON also offers economic advantages, when the long durability and low maintenance are taken into account.

3 Production procedures for SIFCON

Due to the extremely high fibre content in SIFCON the steel fibres cannot be mixed in as usually in a standard concrete mix. So a special method for the SIFCON-production had to be developed [4]. In the first step, the steel fibres are spread direct onto the existing structure, for example a floor slab. This loose filling results automatically in a fibre content of about 10 % by vol..

In the second step the mortar with fluid consistency is infiltrated into the steel fibre bed (Figure 2). For a complete filling the surface is treated with a vibrating screed to improve the infiltration.

Technically no further work would be necessary. However, the steel fibres, which are directly at the surface can corrode and raise rusty spots, which however only are visual blemishes. Nevertheless to prevent such effects an additional cover layer of about 5 to 10 mm of regular mortar is placed fresh in fresh onto the SIFCON layer (figure 3). The final surface can be finished as required individually in each case; e.g. brushing, smoothing etc.. Finally, the SIFCON-area has to be cured carefully.

Fig. 2: Infiltration of the mortar in a fibre bed

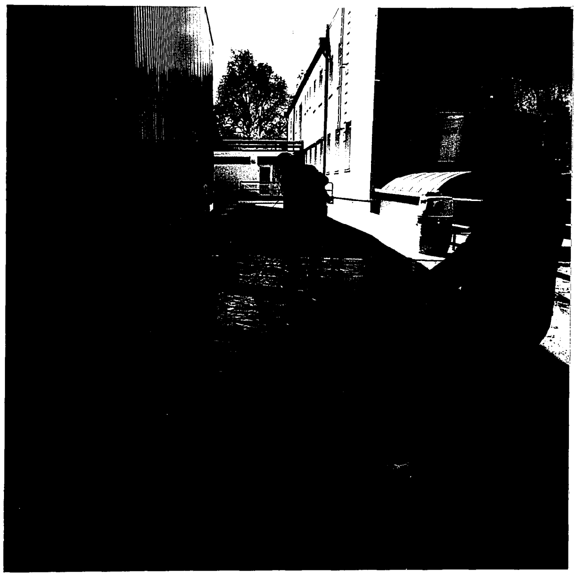

Fig. 3: Addition of the cover layer with regular mortar

4 Constituents and mortar compositions

4.1 Steel fibres

Loose steel fibres must be used to ensure non-compacted filling. Staple-like fibres, 30mm in length and 0.5mm in diameter, have been found very suitable. Short fibres result in a denser structure than long fibres.

4.2 Infiltrating mortar

To enable the complete infiltration of the fibre bed, the mortar must be of fluid consistency and the maximum aggregate size has to be limited to about 0.7mm. For this purpose following mix for the infiltrating mortar has been developed (Table 1):

Table 1: Mixture of infiltrating mortar

Cement	CEM I 52,5 R (high fineness)	kg/m³	1000
Water		kg/m³	330
Aggregate	Silica sand 0/0,7 mm	kg/m³	860
Additive	Superplasticizer (naphtasulfonate)	kg/m³	35
	Stabilizer (artificial silicium dioxide "nanosilica")	kg/m³	10

The very dense microstructure in the hardened mortar especially is obtained by the low w/c-ratio and the addition of silicium dioxide.

It is very important that the mortar has a high homogenity without lumps or segregations. With standard concrete mixers this cannot be guaranteed in all cases. Though special mixers with high speed has to be used.

4.3 Mortar for cover layer

The cover layer, which has to protect the SIFCON-layer from corrosion, doesn't contain any steels fibres. To minimize the tendency of cracking, the mortar has to be optimized with respect to minimal shrinkage. For this purpose in comparison to the infiltrating mortar the maximum aggregate size is enlarged to 5 mm and the cement content is reduced to 600 kg/m^3. A part of the cement (up to 100kg/m³) can be replaced by fly ash. Additionally 6mm long synthetic fibres (polypropylene, polyacylnitrile) are added to contoll the possible crack widths in the surface.

Table 2: Mix of cover layer mortar

Cement	CEM I 52,5 R	kg/m³	600
Water		kg/m³	195
Aggregate	Natural sand 0/2 mm	kg/m³	800
	Crushed basalt 2/5 mm	kg/m³	770
Additives	Superplasticizer	kg/m³	21
	Stabilizer	kg/m³	8
Synth. fibres (l= 6 mm)		kg/m³	6

5 Properties of SIFCON

5.1 Mechanical properties

Due to the high amount of steel fibres SIFCON distinguishes from normal concrete especially in its deformation behaviour and in ductility. With the mortar mentioned in Table 1 SIFCON exceeds a compressive strength after 28 days of about 90 MPa. In other investigations - using infiltrating mortar of normal strength - a significantly increased ductility also in compression tests was prooved (Figure 4) [5].

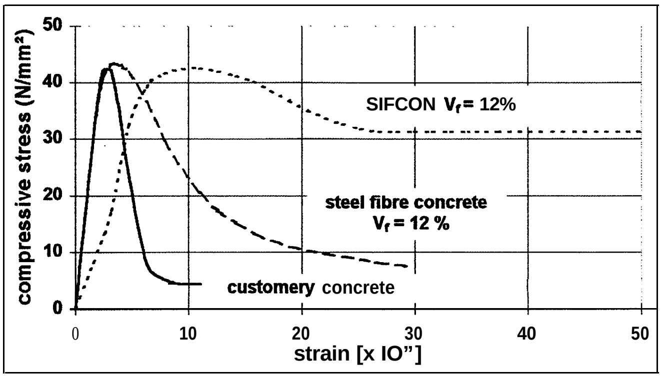

Figure 4: Stress-strain curve of SIFCON under compression (from [5])

In spite of the high compressive strength the modulus of elasticity of SIFCON is distinctly lower than that of ordinary concrete. In extensive studies [3,6] moduli of elasticity between 15000 MPa and 23000 MPa were ascertained, correlating with the flatter stress-strain curve in Figure 4. This mainly results from the small aggregate sizes used in SIFCON. However, a low E-modulus is of advantage for minimization of restraint stresses in the thin layers layers without any joints.

The ductility-increasing effect of the steel fibres can be clearly demonstrated in bending and tension tests [6]. SIFCON samples exceeded flexural strengths between 40 and 45 MPa, which is 6 to 8 times of the values of ordinary concrete. Furthermore, after exceeding the ultimate load the sample does not break. The specimen can be deformed furtheron to a large extend (Figure 5). In this photo also can be seen, that the steel fibre bed is filled completely with the infiltrating mortar.

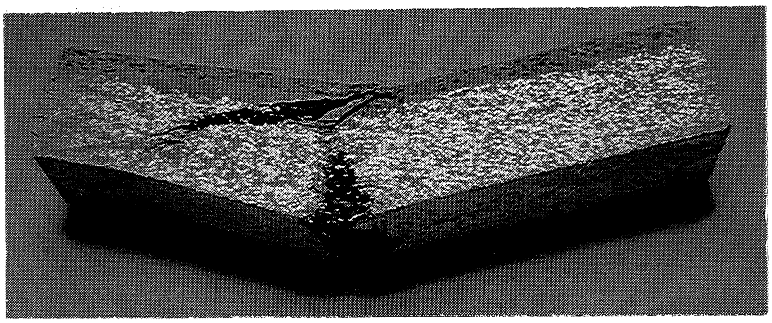

Figure 5: SIFCON sample after bending test

A typical result of a centric tension test is presented in figure 6. A number of strain gauges, displaced in respect to one another, were applied on each sample, to study the deformation behaviour at the main fracture area and at normal zones [7]. While in the real fracture zone (DMS 5) the deformation increases to a very large extend at a high stress level, in the other sections after final break the deformations decrease nearly in a elastic manner.

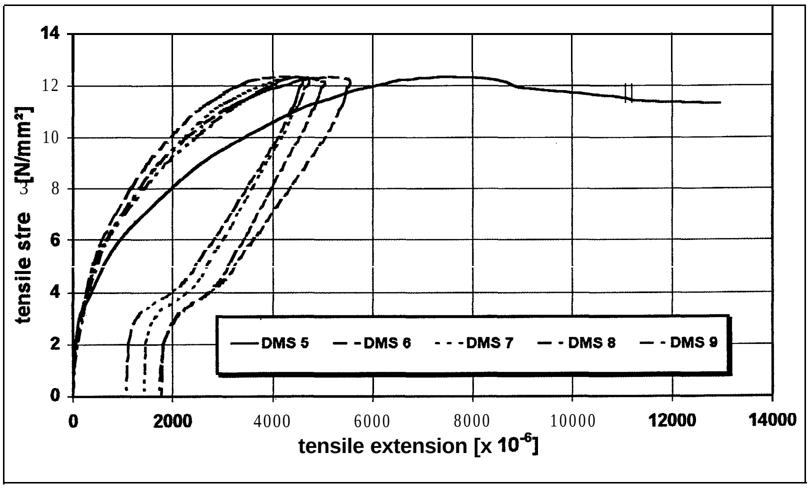

Figure 6: Stress-strain curves of SIFCON under centric tension (from [7])

The special composition of the mortar (w/c-ratio, addition of nanosilica) leads also to a high resistance against abrasion and freeze-thaw. In freeze-salt-tests according to the CDF-method the SIFCON samples after 50 cycles had a loss in mass of about 185 g/m², while in previous experiences values up to 1500 g/m² are accepted. These results show that SIFCON-mortars according table 1 and 2 have a sufficient freeze-salt-resistance also without artificially entrained air pores.

5.2 Tightness

The tightness of SIFCON against the penetration of fluid mediums cannot be proved in the common way. Due to the high amount of steel-fibres the specimens cannot be splitted in normal manner. For this reason penetration tests of SIFCON are carried out on slabs with a thickness of only 5cm. The specific fluid is applied under pressure to the surface. As criterion the time period is determined when the fluid reaches the opposite side. Alternatively the slabs after a fixed test period can be cut, the surfaces are sprayed with sulphuric acid and then heated with a flame to fix the extent of penetration. Details to these tests are shown in [8]. Until now penetration tests have been done with water, acetone, gasoline, diesel and various oils.

Based on these investigations, it could be proved that a SIFCON-layer of 45mm in thickness fulfills the requirements according to the German guideline “Concrete construction and water polluting fluids” (DAfStb) for protection against a single penetration (accidental event). In the case of an intermittent penetration, for example at gasoline stations, the thickness of the SIFCON layer must be at least 8 cm [9].

6 Details for Construction

The high ductility of SIFCON allows constructions of large areas without any joints. All deformations which normally take place within a construction joint are converted into deformations within a very large number of small cracks. Nevertheless;- joints cannot be prevented in all cases (e.g. between various working sections). However, such joints can be connected homogeneously. For this purpose the edges of a sectional layer are fixed by an angled formwork. As soon as the infiltrating mortar has set sufficiently the formwork is removed and the mortar along the edge is washed out at the surface, so that the fibres in the edge are partly set fee and partly fixed in the already constructed SIFCON layer. To continue the layer, new fibres are spread right against this edge and the mortar is poured in the next step. Samples taken from the joints show no structural discontinuity. In bending tests the main fracture even appeared outside the joint. Nevertheless, if a joint should open in an exceptional case, the crack can be grouted easily and permanently with a suspension of cementlime.

As every cement-bound system the infiltrating mortar of SIFCON also shrinks. However, these deformations are restrained to a large extend by the steel fibres so that the shrinkage deformations of the SIFCON system in generell are relative small.

Warping of the layer due to shrinkage gradients or a horizontal flaking at the edges can be prevented by bolts, which are fixed in the existing subbase and are bound completely into the SIFCON layer. Due to these anchors and the high bond between the SIFCON-mortar and the subbase high restraint stresses are raised which are absorbed by the formation of the very small cracks.

For retaining basins additional surrounding walls or edges have to be built around the sealed hoizontal areas. These can be constructed with SIFCON, too. For this purpose the infiltrating mortar is washed out at the base joint as mentioned above or additional steel fibres are spread into the still fresh mortar. Then into a formwork of the basin walls separate layers of steel fibres of about 5 to 10 cm are spread and infiltrated with mortar. The formwork should be vibrated to improve the infiltration. By repeating these steps also high vertikal walls can be constructed with SIFCON.

7 Practical Applications

At the end of the 70's special high-performance components were produced with SIFCON in the USA, for example safes, repairs of highways and bridges, prefabricated beams and silos for ammunition and rockets [1,2].

In Germany SIFCON first time was used by Philipp Holzmann to repair and upgrade a 1200 m^2 large industrial area [10], where chemical products are handled and stored, according to the requirements of the German environmental laws. The existing subbase consisted of reinforced concrete jointed slabs, each 5x5m. Most slabs showed large cracks. The whole existing concrete area was cleaned by high-pressure water jetting before the steel fibres were spread. By this preparation the required bond between SIFCON and the existing concrete was achieved, which could be proved afterwards on cores. The retaining basin was built as described in paragraphs 3 and 6.

In a similar project, various slabs in the basement of an old chemical chlorine production plant, were sealed to comply with the requirements. The basement floors of tiles and concrete and similar surfaces were directly covered with a SIFCON layer. A wall section in a garbage chute, which had to absorb the impact of the grabbers, was covered with SIFCON 1.0 m high and 8 cm in thickness. Single layers of 20cm steel fibres were spread into the formwork in one step and subsequently infiltrated. Step by step using this method the total heigth was obtained.

Considering the high resistance against abrasion and freeze-salt-attacks SIFCON can be used also very adventageously for repair workson highways, bridges or other public areas. One successful application was the repair work of bus stops in Berlin. Common materials like asphalt and polymer concrete have proven unsuitable on the approaches of bridges due to the braking and acceleration of busses. Also repair work on a highway with a concrete pavement were performed successfully with SIFCON.

8 References

1. Schneider, B. (1992) *Development of SIFCON through applications,* Proceedings of the RILEM/ACI-workshop "High Performance Fibre Reinforced Cement Composites", Mainz 1991, E&FN SPON, London, etc., pp 177-194
2. Lankard, D.R. (1992) *Manufacture of SIFCA Composites precast shapes,* Proceedings of the RILEM/ACI-workshop "High Performance Fibre Reinforced Cement Composites", Mainz 1991, E&FN SPON, London, etc., pp 195-202
3. Naaman, A.E. (1992) *Tailored properties for structural performance,* Proceedings of the RILEM/ACI-workshop "High Performance Fibre Reinforced Cement Composites", Mainz 199 1, E&FN SPON, London, etc., pp 18-38
4. Breitenbiicher, R., Wdrner, J.D. (1995) *Ein neuer Hochleistungsbeton,* beton 45, no. 12, pp 861-866
5. Wdrner J.D., Regtuijt, B.H. (1990) *Hochfester Faserbeton, Tastversuche,* Darmstädter Massivbau-Seminar, Vol. 3, Institut für Massivbau, Techn. University of Darmstadt
6. Wörner, J.D., Lemberg, M. (1995) *Hochfester Faserbeton:* Final Report of DBV-Research Project 16 1, Techn. University of Darmstadt
7. Philipp Holzmann AG (1995) *Zugversuche von SIFCON,* B 56-1201 of the Central Laboratory, Neu-Isenburg
8. Lemberg, M. (1995) *Dichtschichten aus hochfestem Faserbeton,* Dissertation, TH Darmstadt
9. Deutscher Ausschuß für Stahlbeton (1996) *Richtlinie für Betonbau beim Umgang mit wassergefahrdenden Stoffen,* Beuth-Verlag Berlin
10. Mayer, L. (1995) *Neue Entwicklungen beim Einsatz von Hochleistungsbeton,* Lecture at Deutscher Betontag Hamburg, Proceedings Deutscher Beton Verein E.V.

Application of Life Cycle Assessment (LCA) to Urban Renewal Projects

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Abstract

One important challenge for the industry is to reduce the impact of construction on the global environment, and most of the burden placed on the environment by construction is produced in urban areas. For this reason, there has been much interest in the application of a suitable, long-term method of environmental impact assessment to urban development and urban renewal projects.

The Life Cycle Assessment (LCA) method is believed to be highly effective for such purposes. Several approaches utilizing this method have already been developed and applied to individual buildings, and the results of such analyses have come to be reported in the literature. Yet, there have been very few cases in which an expanded version of the LCA method has been applied to urban structures overall.

The authors have developed a method of applying LCA to the downtown areas of large cities. This method enables comparisons of environmental load between (a) cases of natural renewal, in which the collection of urban structures is merely left as is, and (b) cases of planned renewal, in which various approaches are used to give a project directionality and consistency.

Four quantities were selected as indices for the environmental aspects of the analysis . -- material usage, energy consumption, carbon dioxide emissions, and construction waste discharge. These indices are vital for assessing efforts to prevent global warming, suppress the "heat island" effect in large cities, and, in response to an especially serious problem in Japan, reduce the amount of waste generated at construction sites.

While the authors envision that their method of analysis will be able to be applied in a universal manner to all major Japanese cities, as a first step they elected to apply the model to a specific urban region and, accordingly, chose the western district of Nakanoshima, a big renewal project progressing area in downtown Osaka. The authors then began to analyze the above mentioned life cycle environmental aspects of that district.

Keywords: global warming, LCA, urban renewal

1 Research Background and Conceptual Framework

As the problems of global warming become manifest, there is an increasing interest in societal systems that place relatively little load on the environment. Reducing the burden on the global environment is a vital issue that the construction industry must address in response. Most environmental loading from construction activities occurs in urban areas, where buildings and civil structures are concentrated. Consequently, there has been much interest in the application of a suitable, long-term method of environmental impact assessment to urban development and urban renewal projects.

Our research effort is focused on the analysis of urban renewal projects in the central areas of large cities. As depicted in Fig. 1, it is currently being implemented in three parts -- an environmental assessment system which estimates environmental load by existing urban structures and renewal process, a strategic alternative planning system which proposes low environmental load methods by changing planning variables, and a computer-aided research and development system which handles imformations with user-friendly interface. Presented in this paper is an outline of the . environmental assessment system.

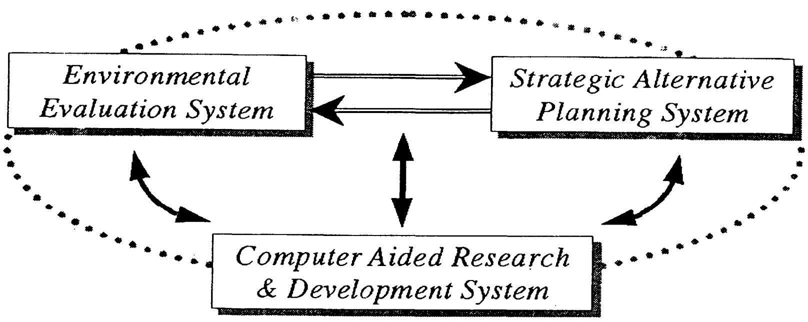


Figure 1. Research Organization

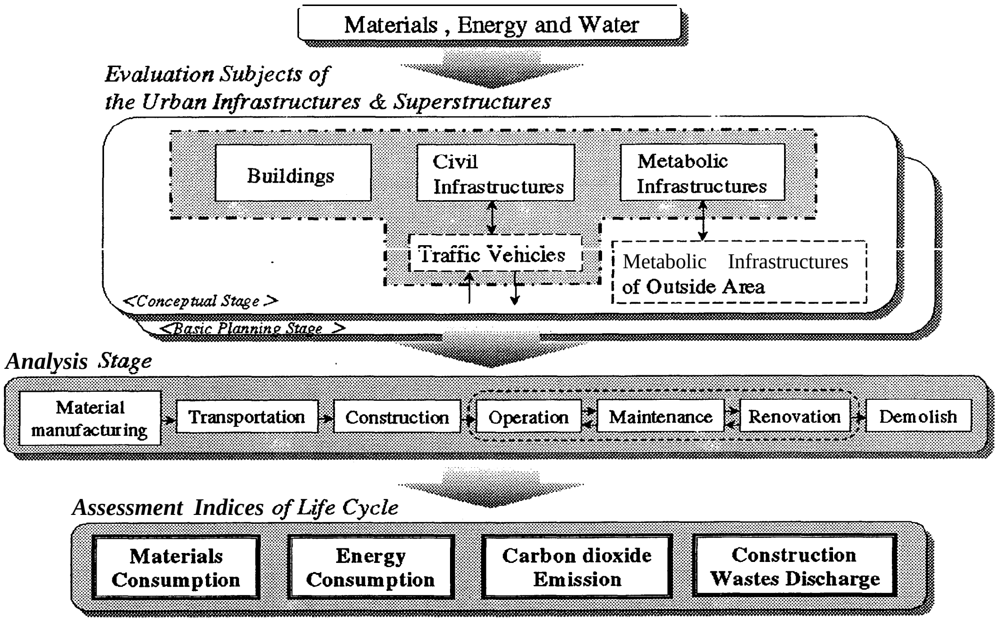
2 Environmental Assessment System

The Life Cycle Assessment (LCA) method is believed to be highly effective for the analysis of long-term environmental loading. Several approaches utilizing this method have already been developed and applied to individual buildings. The results of such analyses have come to be reported in the literature [1], and reports of test calculations for some civil engineering structures are also beginning to appear [2]. Yet, there have been very few cases in which an expanded and general version of the LCA method has been applied to an overall collection of urban super and infra structures.

We have developed an LCA method for application to the downtown areas of large cities. This method enables comparisons of environmental load between (a) cases of natural renewal, in which the collection of urban structures is merely left as is, and (b) cases of planned renewal, in which various approaches are used to give a project directionality and consistency.

As illustrated in Fig. 2, the assessment system is comprised of three components -- an evaluation subjects, an analysis stage, and assessment indices. Into the evaluation subject component, we enteredsuperstructural, infrastructural elements, and the like for the district to be analyzed. We also included taffic vehicles, and a portion of activities external to the district, such as broader infrastructural systems to be borne by that district. The analysis stage was divided into seven steps corresponding to the seven life cycle stages, and the analysis was carried out accordingly.

Four quantities were selected as indices for the environmental aspects of the analysis -- material usage, energy consumption, carbon dioxide emissions, and construction waste discharge. These indices are vital for assessing efforts to prevent global warming, suppress the "heat island" effect in large cities, and, in response to an especially serious problem in Japan, reduce the amount of waste generated at construction sites. Partially because of the difficulties that would be involved in obtaining clear and objective data for other potential environmental aspects, we only included the four indices above in this analysis.



※ "Metabolic Infrastructures" means Supply-Treatment and Communication Infrastructures

Figure 2. The Structure of Environmental Evaluation System

3 Inventory of the Urban Structures Complex

An important prerequisite for the general application of the LCA method to urban areas is that the structural elements making up that area be hierarchically classified. Here, we arranged and classified the collection of structures making up a typical urban area and then created a detailed, hiearchically arranged list of their compositional elements (thereby, in effect, taking an inventory of urban structures). Furthermore, as the results of this research are envisioned for use in the planning stage, it is necessary to be able to perform the actual calculations with only the general data available at the basic conceptualization stage for the district and the basic planning stage for the structures (or, conversely, it may not be necessary to carry out highly precise analyses based on detailed design data for the structures).

Utilizing the arrangement shown in Fig. 3, we created an actual inventory by filling in the detailed data fields one after the other (some of the data is still being collected). The environmental load produced by metabolic infrastructures (e.g., water and sewage systems) is assigned to the district in proportion to demand occurring within the district. To facilitate the analysis of strategic alternative plans, we included manipulable variables in the inventory for those entries likely to have a large effect.

4 Methods and Results of Calculations for Unit Quantities

Several unit quantities have been proposed for the amount of energy consumed and the amount of carbon dioxide given off during the manufacture of construction materials.

As for the unit quantity of carbon dioxide, we utilized values tentatively recommended by the Japan Society of Civil Engineers and shown in Table 1 [3]. These values are utilized as basic data for reference input output table of Japan, incorporate a partial application of simple additive approach, and include ripple effects between industries.

Unit material usage for construction and unit energy utilization (building use) stages was determined by statistically processing past operating data. Energy consumption in the utilization stage accounts for the highest proportion in the entire LCA; and, with an output value sensitively dependent on its input value, much precision is required in its estimation. Here, we developed a database to meet this requirement.

Little data has been presented on unit construction waste generation, and for this reason we prepared estimates using industry statistical values.

Table 1. CO2 Unit Emission

Classification	CO2 Emissions *	Unit	Classification	CO2 Emissions *	Unit
Gravel & Quarried stone	0.00154	[kg-C/kg]	Rubber(tire)	1.20	[kg-C/kg]
Crushed stone	0.00189	[kg-C/kg]	Paints	0.452	[kg-C/kg]
Wood ·Swan lumber ·Plywood	 0.0297 0.0519	 [kg-C/kg] [kg-C/kg]	Construction machine	1.52	[kg-C/kg]
Cement ·Portland ·45% slug mixed	 0.228 0.135	 [kg-C/kg] [kg-C/kg]	General-purpose machine	1.21	[kg-C/kg]
Ready mixed concrete	84.9	[kg-C/m^3]	Temporary equipment & materials	lifetime:10year	
Steel ·New ·Recycle	 0.411 0.128	 [kg-C/kg] [kg-C/kg]	Gas oil	0.779	[kg-C/l]
Aluminum(sash)	2.03	[kg-C/kg]	LNG	0.669	[kg-C/m^3]
Ceramics	0.188	[kg-C/kg]	LPG	0.868	[kg-C/kg]
Glass(plate)	0.486	[kg-C/kg]	Electric power	0.129	[kg-C/kWh]
Plastics	0.492	[kg-C/kg]	Transportation	0.0930	[kg-C/t·km]
Asphalt ·Asphalt ·Mixture for asphalt pavement	 0.0281 0.0113	 [kg-C/kg] [kg-C/kg]	* Recommendation value of Japan Society of Civil Engineers		

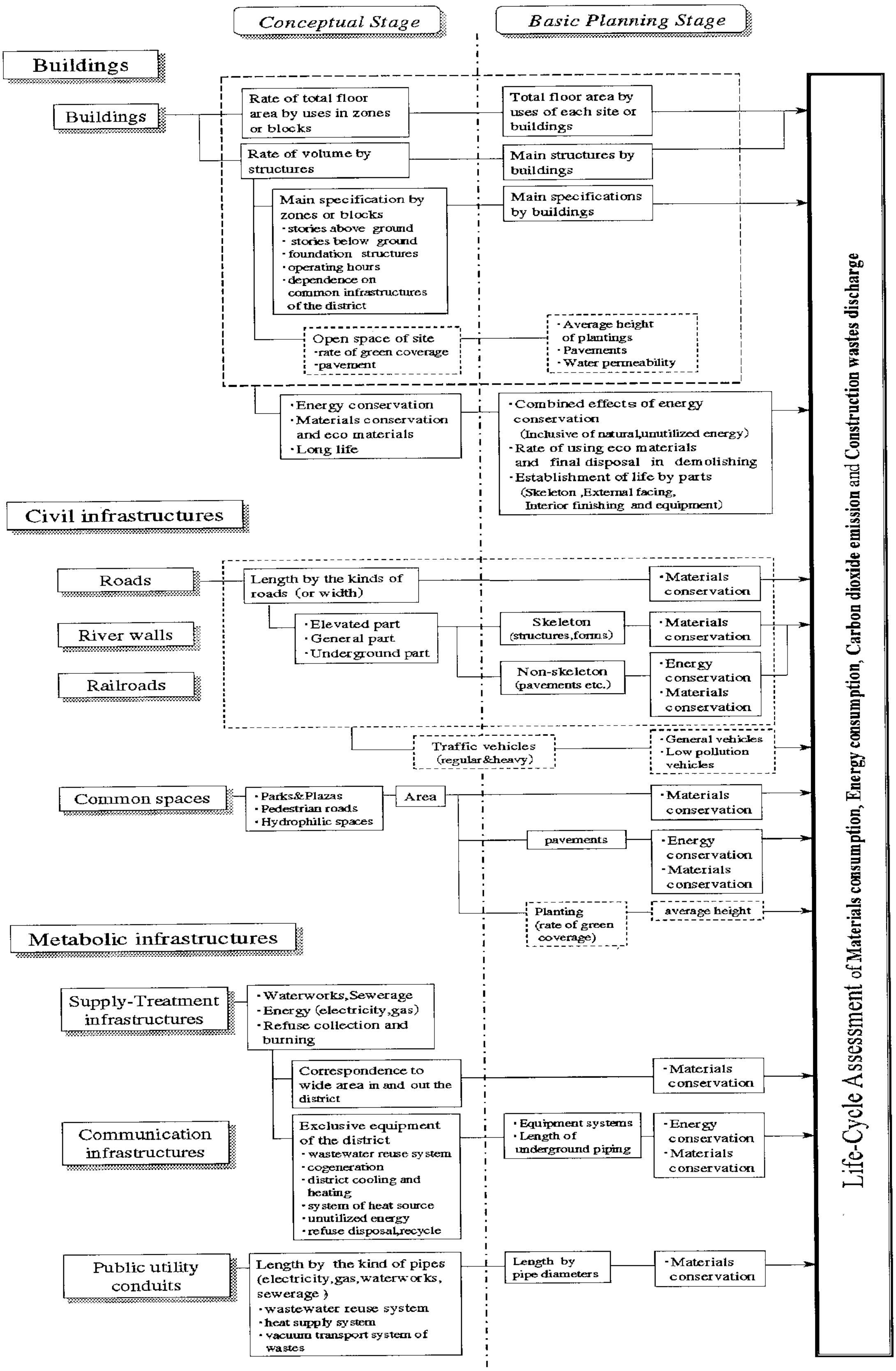


Figure 3. The Inventory of the Accumulated Urban Infrastructures & Superstructures

5 Western District of Nakanoshima -- current state and LCA results

We envision that our method of analysis will be able to be applied in a universal manner to all major Japanese cities. Yet,. as a first step, we decided to select a specific urban region and configure an assessment system modeled on that region. Here, we chose the western district of Nakanoshima, a central business hub in the City of Osaka, a representative large Japanese metropolis.

As is apparent in Fig. 4, the western district of Nakanoshima is enclosed within two rivers and is comprised of (a) an area that contains a great profusion of commercial and business facilities and (b) an area that mostly contains an old college campus , small housings and a number of warehouses. Currently, the state of development in Nakanoshima varies greatly by district; and, even within the warehouse district, several large office buildings are currently under construction.

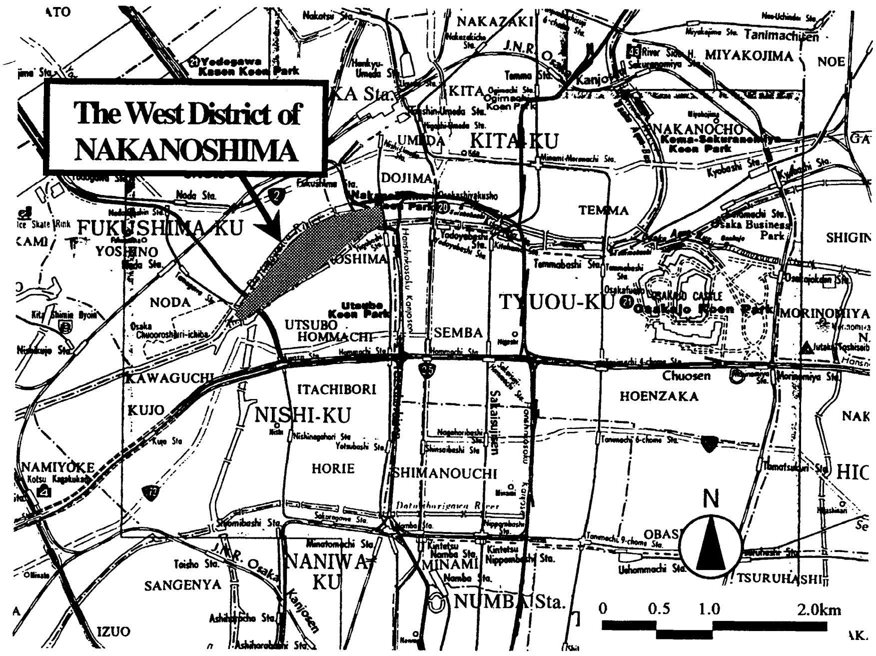
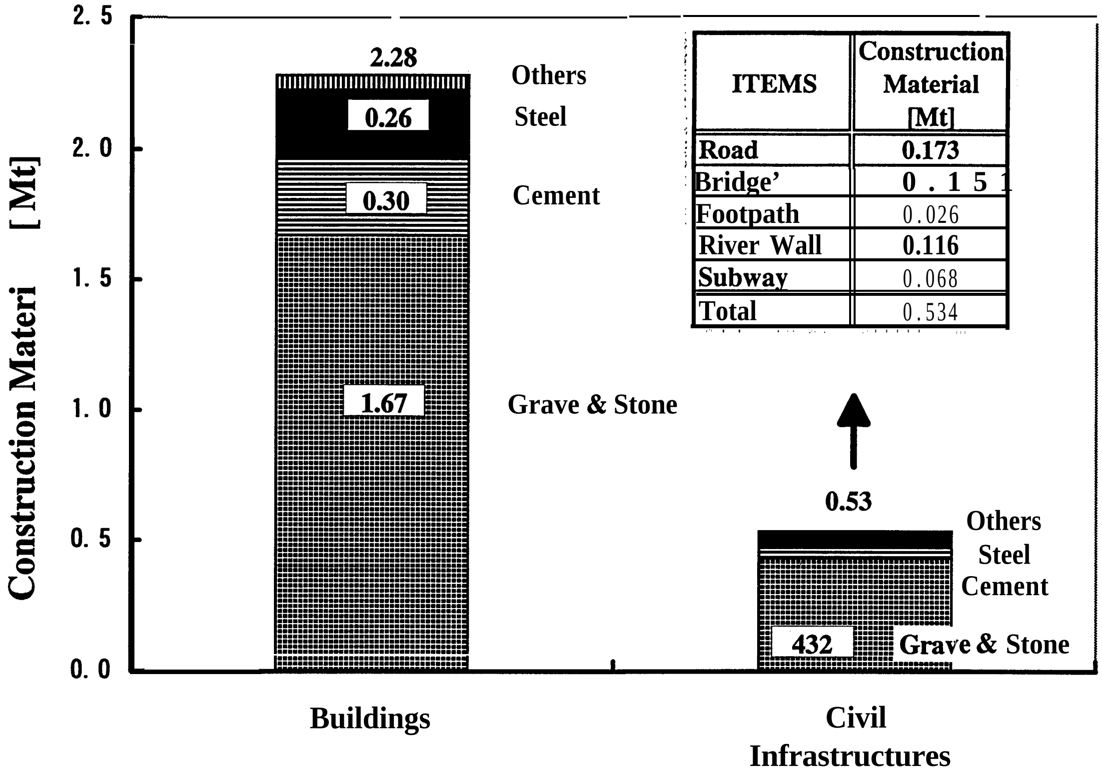


Figure 4. Osaka, the West Distric of Nakanoshima

The total area of the district covered in this analysis is 33 ha, the total number of buildings in the district is approximately100, and the total floor area of those buildings is 778,510 m². Also in the district are 1,126 m (total length) of bridges, 4,991 m (total) of general roads, 1,252 m (total) of expressways, 768 m (total) of subways, and 2,843 m (total) of sea walls.

The consumption of construction materials in the district covered in this analysis is shown in Fig. 5. Fig. 6 presents estimates of the amount of carbon dioxide given off over the life cycle of these materials based on the average service life of current buildings and civil engineering structures.

Because we are still working to determine unit values for construction waste disposal, we are unable to present corresponding ‘results for construction waste volume at this time.



ITEMS	Construction Material [Mt]
Road	0.173
Bridge'	0 . 1 5 1
Footpath	0.026
River Wall	0.116
Subway	0.068
Total	0.534

Figure 5. Construction Materials

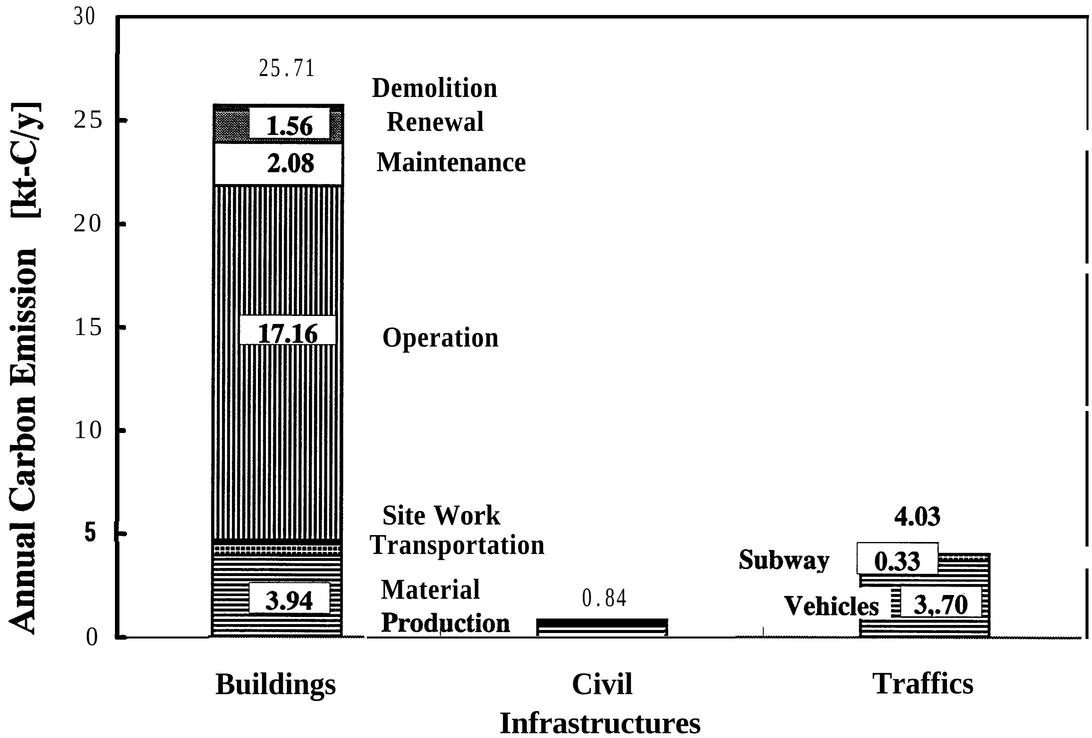


Figure 6. Life Cycle Carbon Emission

6 Conclusion

We have developed a method by which one can easily determine the long-term environmental load imparted by superstructures and infrastructures in downtown areas of large cities. This method facilitates the study and comparison of environmental load in and among (a) cases of natural renewal, in which the collection of urban structures is merely left as is, and (b) cases of planned renewal, in which various approaches are used to give a project directionality and consistency.

Four quantities were selected as indices for the environmental aspects of the analysis -- material usage, energy consumption, carbon dioxide emissions, and construction waste discharge. These indices can serve as a powerful means of assessing efforts to address the environmental problems typically encountered by cities.

While we envision that our method of analysis will be able to be applied in a universal manner to all major Japanese cities, as a first step we elected to apply the method to a central business hub in the City of Osaka, a representative large Japanese metropolis. We then began to analyze the above mentioned environmental aspects of area district over its life cycle. We found that, in the district covered by our analysis, the load relating to the operation(building use) stage accounts for a large proportion of the total.

From here, we plan to expand our numerical capabilities and conduct comparative calculations for cases incorporating a variety of concrete alternative plans for urban renewal projects.

Acknowledgements

We would like to express our appreciation to CREST (Core Research for Evolutional Science and Technology) of Japan Science and Technology Corporation (JST), for their encouragement and support in the advancement of this research.

References

1. K. Takemoto, K. Sakai. (1997) Life Cycle CO2 Emission from the Buildings and the Restrain Means, Second International Conference Buildings and the Environment, CIB TG-8, pp. 469-476.
2. T. Morioka. (1996) Scheme and Practices of Life-cycle Assessment in Civil and Construction Systems, Pre-prints of the 4th Symposium on Global Environment, Committee on Global Environment / Japan Society of Civil Engineers, pp. 29-34.
3. K. Sakai. (1996) ibid. pp. 43-48.

Life Cycle Assessment and Indoor Environment Assessment

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Abstract
Life Cycle Assessment (LCA) is frequently used as a tool for environmental assessment of buildings and building materials. Generally, the main focus of LCA is impact on the regional and global external environment. However, a considerable part of the environmental problems related to the building sector arise locally in connection with the indoor environment, like effects on human health. The study deals with what environmental issues arise for the external and indoor environment, respectively, in the building sector, how these issues relate to each other and whether some issues connected with the indoor environment may be included in an LCA. The study is mainly based on data from an LCA of three flooring materials (linoleum, vinyl flooring and solid wood flooring) and on measurements of indoor air emissions from these flooring materials. Methodological issues are pursued.

Keywords
building materials, buildings, floorings, LCA, life cycle assessment, indoor climate, SBS, VOC

1 Introduction

Life Cycle Assessment (LCA) is frequently used as a tool for environmental assessment of buildings and building materials. Generally, the main focus of LCA is impact on the regional and global external environment. However, a considerable part of the environmental problems related to the building sector arise locally in connection with the indoor environment, like effects on human health.

Research about the environmental impact from buildings and building materials has been performed separately for external and indoor issues respectively, and today this research is continued within two separate disciplines. In the last years, an increasing number of tools for environmental assessment have been developed. When constructing a new building today and when environmental concern is focused, there is generally a desire to minimise the total environmental impact on the external environment and the indoor climate at the same time, but there is a lack of knowledge on how improvements in one area affect the other. Hence, there is a need to map the correspondence between indoor and external environmental issues.

Final results of the study are not yet available. A report containing background data, final results and complete references will be published in spring 1998 [1].

1.1 Aims and objectives

The study deals with what environmental issues arise for the external and indoor environment, respectively, in the building sector, how these issues relate to each other, how they are dealt with in environmental assessment methods used today and whether some issues connected with effects of the indoor climate on human health may be included in an LCA.

1.2 Scope

Some main system boundaries and delimitations of the study are:

- flooring materials were chosen as object of the study
- the study mainly focuses on Volatile Organic Compounds (VOCs) as this is the environmental load most frequently considered when trying to assess the environmental impact on the indoor climate from flooring materials. Also, VOC is a parameter that occurs in several steps of the life cycle of flooring materials, both in connection with industrial processes, transports and the user phase
- non-industrial indoor environment was studied
- only LCA was included of existing methods dealing with impact on the external environment. However, some of the conclusions may also be valid for other methods.

The conclusions are partly based on data from an LCA case study of three flooring materials (linoleum, vinyl flooring and solid wood flooring) and on measurements of indoor air emissions from these flooring materials. Also, existing research in the fields of LCA, environmental assessment of building materials and buildings, VOC, indoor climate and human health was used to answer the questions above.

2 LCA , indoor environment assessment and VOCs

This section gives a brief theoretical background for what characterises LCA, indoor environment assessment and VOC measurements.

LCA is a method for analysing and assessing the environmental impact of a material, product or service throughout its entire life cycle, usually from the acquisition of raw materials to waste disposal. The environmental parameter groups most commonly accounted for in LCA are use of materials, use of energy, emissions to air and water and waste generation. International standardisation work on LCA takes place under the auspices of the IS0 [2]. The methodology of LCA is a systems analysis and generally consists of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation of results. Generally, LCA input data and results have the following characteristics:

- the results are product oriented
- regional/global effects on the external environment are mainly focused
- input data consist of environmental loads (total dose), and mainly quantitative information is used
- in the improvement assessment, inventory data alone (environmental loads) may be sufficient for an evaluation, and when this is not the case the environmental impact of these loads may be assessed.

Indoor climate is a term used for describing physical factors in *the indoor environment,* like temperature, ventilation, humidity, air content of particles and gases, lighting and noise. The *indoor air quality* is one of the factors that affect the indoor environment, and it may be assessed by measuring what substances are present in the air (see for example [3]). Building materials is one of several emission sources that affect the indoor air quality. When, in a specific building, a larger quantity of users than may be expected have certain health symptoms (headache, itching, dry skin, eye irritation etc.) the term *Sick Building Syndrome (SBS)* is used. The indoor air quality is generally considered to be closely related to SBS, and emissions from building materials are often mentioned as one of the reasons for “sick” buildings. However, there is today no consensus on what health effects are linked to building material emissions, and how important these health effects are. Only in exceptional cases has a connection been found between SBS symptoms and the presence of specific building materials or building constructions. Factors that have been shown to influence the rate of SBS symptoms are cleaning conditions, occurrence of copying machines, insufficient ventilation, damage caused by damp and mould and occurrence of putty with a casein content etc.. Primary data and results used in indoor environment assessment may be characterised in the following way:

- the results are building related and site specific
- human health effects are focused
- the aim is often to improve a deficient indoor climate in an existing building

- input data for discovering the problem are generally qualitative and effect oriented, while in the improvement assessment both qualitative and quantitative information is used.

When studying the environmental impact from building materials during the user phase, *Volatile Organic Compounds (VOCs)* are frequently used as a measure, generally defined as those organic compounds that have a boiling point in the interval from 50-100 to 240-260°C. VOCs are regarded to affect the external regional and global environment as well as human health directly. For indoor air the VOC mixture is often expressed as Total Volatile Organic Compounds (TVOCs). As there is today a large variety of ways to calculate a TVOC value and there is no standardised procedure for how to do this, published TVOC data are often not comparable. Odour, sensory irritation and perception of discomfort are the main potiential health effects of VOCs indoors (see for example [4]). According to some sources, no clear difference in VOC concentrations has been found between "sick" and "healthy" buildings. It is today not possible to conclude that health effects like sensory irritation are associated with the concentration of TVOCs at normal exposure levels in non-industrial indoor environments. VOC emissons also have an important impact on the external environment as they contribute to an increased formation of ozone which will affect human health, cause damage on eco-systems like forests and agriculture and also inflict on global effects like the greenhouse effect. Some significant features for assessment of building related VOCs are:

- VOC measurements may be related both to a product (for example one m^2 flooring during a specific time period) and the indoor climate (as concentration in indoor air)
- the parameter is used both in a life cycle perspective and during the user phase
- human health effects in indoor climate and work environment are generally focused.

3 Including external and indoor environment in one method - State of the art

In last years, methods have been developed for assessing and comparing the environmental impact of building materials and buildings. It was studied if and how human health aspects were considered by some of these methods.

According to IS0 among others, the three general categories of environmental impacts that need consideration in an *LCA* include resource use, human health and ecological consequences. It may be concluded that, principally, LCA should include impacts on human health, both regarding occupational and work environments. Several actors working with LCA methodology have tried to include work environment issues in **LCA,** and various approaches are available for doing this [5]. However, not much has yet been done to include indoor climate in LCA. When it comes to the impact assessment step, several weighting methods have indices for VOC emissions, generally with the aim to decrease the impact on the global/regional external environment. Methodologically, it would be possible to include VOC indices based on local human health effects in LCA. Thorough knowledge would then be needed about what is the connection between VOC emissions and specific health effects.

Eco-labelling is one of the methods used today for minimising the environmental impact of building materials. The Svanen criteria document for flooring materials [6] is one such example. The document does not clearly account for what environmental issues are primarily considered. However, the intention is to consider factors that are of *major importance during the life cycle* of the flooring, that are *easy to measure* and that are *relatively easy for flooring manufacturers to influence.* VOC emissions are restricted in one aspect; a limit value is set for VOC emissions per m^2. This refers to the manufacturing process only, and nothing is stated about VOC emissions during use of the floorings.

As an example on the building level, *BREEAM* [7] was developed to set criteria for good environmental performance in buildings. This method seeks to minimise the adverse effects on the *global* and *local* environment while promoting a *healthy indoor environment.* Items are included for which there is *good evidence of the environmental problems they cause,* for which *performance criteria can be defined,* and which *can readily be assessed at the design stage.* The environmental issues covered are grouped under three main headings: global issues and use of resources, local issues and indoor issues. All indoor issues relate to human health, and mostly raise absolute demands on the whole building. No issues take VOC emissions into account, except for one criterium regulating formaldehyde emissions. The functional unit used for the final assessment is the whole building. However, for each criterium a specific functional unit is used (i.e. the environmental impact is assessed per m^2, per kWh, as volume percentage etc.). Also, some credit requirements are defined for the whole building, especially regarding local issues.

It may be concluded that several methods for building related environmental assessment include issues regarding both the external and the indoor environment. It is not always made clear what environmental issues are the main objective of the method and how external and indoor environment issues are weighted for the final results.

4 Empirical analysis

An *LCA **of** flooring materials* was performed at Chalmers University of Technology (CTH), in which the environmental impact of linoleum, vinyl flooring and solid wood flooring during their life cycles was assessed and compared [8]. Only impacts on the external environment were studied, and local indoor effects on human health were omitted. The parameter categories included to present the environmental load were use of resources, use of energy, emissions to air and water and waste generation. Values for VOC emissions obtained in the inventory were sometimes available as specific VOCs and sometimes as TVOC values. According to the inventory, linoleum caused the highest TVOC emissions and solid wood flooring the lowest. However, the difference between the floorings was not large, considering the data uncertainty. The quantitative results of the inventory analysis were then evaluated by using three weighting methods. According to the results from the impact assessment, the impact of VOCs was moderate compared with the total environmental impact, except for solid wood where terpene was the main contributing VOC parameter.

Another *case* study was performed at the Swedish National Testing and Research Institute (SP) [9]. The flooring materials vinyl, linoleum and wood were studied with respect to their *VOC emissions during the user phase*. Measurements were carried on for up to two years, depending on the material. The measurements were performed with a small model test chamber, FLEC (Field and Laboratory Emission Cell). The study was limited to measuring VOC, both as TVOC and as specific main components. Total VOC emissions during the user phase were then assessed, based on some assumed conditions regarding user time, room size etc.. There was a great difference between the floorings regarding what specific VOCs dominated the TVOC measure.

Based on the two case studies, the VOC emissions during the user phase were compared both over the life cycle for each flooring type and related to the total environmental impact of the life cycle of the floorings. It was found that TVOC material emissions during the user phase were of the same magnitude as for the rest of the life cycle. For the solid wood flooring, VOC emissions during the user phase far exceeded VOC emissions during the rest of the life cycle. Three weighting methods were then used to assess the importance of the VOC emissions from the user phase in a life cycle perspective. It could be seen that the user phase had a relatively small contribution to the total environmental impact of the floorings. Only for solid wood did the material emissions of the user phase play a significant role.

Some calculations were made, based on the case studies, literature data and some assumed conditions:

- the relative importance of VOC emissions from floorings for the VOC content in indoor air was assessed
- the contribution of VOCs from indoor air to the external environment was estimated, especially the contribution related to floorings and other building materials
- total VOCs from indoor air were compared with total statistical VOC emissions to the external environment.

5 Discussion and conclusions

Different approaches for building related environmental assessment were compared, and differences and similarities were discussed. Table 1 summarises some main characteristics for LCA, material emissions and indoor environment assessment.

	Life cycle assessment	Material emissions (VOC)	Indoor environmental assessment
Primary data	Dose Quantitative Measurements, calculations Independent of site	Concentrations Quantitative Measurements Site specific	Concentrations, health effects Quantitative, qualitative Measurements, experience Site specific
Environmental problems/effects	Regional, global External environment Contribution Exposure independent	Local Human health Contribution Exposure dependent	Local Human health Whole effect Exposure dependent
Functional unit	Building material, building	Building material	Building, individual
Life cycle steps	Whole life cycle	User phase	User phase
Influencing actors	Whole life cycle	Whole life cycle	Whole life cycle
Influenced actors	All	Users of the building	Users of the building
Results	Loads, effects	Loads	Effects

Table 1. Metodological comparison of LCA, material emissions and indoor climate related effects. Most significant characteristics are presented.

The final results of this study are yet to be published. However, some preliminary conclusions were drawn.

For the studied floorings, the VOC material emissions during the user phase were of the same magnitude as those related to the remaining life cycle. However, the impact of these emissions was marginal in a life cycle perspective when comparing it with the total environmental impact of the floorings.

Some methods for environmental assessment of buildings and building materials include criteria dealing with both external and indoor environment issues. Then for the final results external and indoor environment issues are evaluated either integrated or separated. It is not always made clear what environmental issues are the main objective of the method and how external and indoor environment issues have been weighted in the final results.

Methodologically, it would be possible to include indoor climate issues in the impact assessment step of building related LCA. However, no scientifically verified methods are today available for weighting effects on the external and indoor environment against one another. For building materials there is today no consensus on what health effects are linked to material emissions and how important these health effects are. The indoor environment is affected by the qualities of the building rather than by choice of specific building materials. Hence, issues concerning indoor environment effects on human health may be included in LCA of the whole building rather than in LCA of building materials.

In product related environmental assessment like LCA, environmental loads from processes and transports that may be related to the product are primarily taken into account. Likewise, in human health related environmental assessment like indoor environment assessment, data are primarily used that may easily be related to human health and the indoor climate of a specific building. It is hard to include these two approaches in the same method without making one of the approaches less effective. The method of LCA is not well suited to minimise either local health effects or regional/global total emissions, like national environmental goals.

Acknowledgements

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References

1. Jönsson, Å. (1998) *Life Cycle Assessment and Indoor Climate,* Report 1998:X, Technical Environmental Planning, CTH (Chalmers University of Technology), Goteborg (to be published).
2. IS0 *(1997). IS0 14040. Environmental management - Life cycle assessment - Principles and framework,* First Edition 1997-06-15, IS0 (the International Organization for Standardization), Switzerland.
3. Sundell, J. and Kjellman, M. (1994) *Luften vi andas inomhus,* Publication 1994: 16, Folkhalsoinstitutet, Stockholm.
4. Berglund, B. and Johansson, *I.* (1996) *Health Effects of Volatile Organic Compounds in Indoor Air,* Archives of the Center for Sensory Research, Volume 3, Issue 1: 1996, Dep. Of Psychology, Stockholm University, Stockholm.
5. Potting, J., Torgius Möller, B. and Astrup Jensen, A. (1997) *Work environment and LCA.* LCANET Theme Report, Söborg, Denmark.
6. (1997) *Ecolabelling of Floorings,* Criteria document (Version 2.0), Nordic Council of Ministers.
7. *(1993) BREEAM (Building Research Establishment Environmental Assessment Method), New Offices,* Version 1/93, BRE (Building Research Establishment), Watford, England.
8. Jönsson, Å. (1995) *Life Cycle Assessment **of** Flooring Materials. A case study and methodological considerations,* Licentiate Thesis, Report 1995:3, Technical Environmental Planning, CTH (Chalmers University of Technology), Goteborg.
9. Johnson, L. (1995) *Miljöbedömning av byggmaterial under brukarperioden,* Report 1995:46, SP (Swedish National Testing and Research Institute), Borås.

Integrated life cycle design of materials and structures

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Abstract
Integrated life cycle design is an important tool for sustainable civil engineering. It aims to concretise the multiple requirements of functionality, economy, resistance, aesthetics and ecology into technical specifications and further into designs of materials and structures. With this objective in mind we have to extend the scope of structural design and develop the design process. The extended design must also include multiple calculation methods in which calculations of life cycle monetary economy are added to those of life-cycle natural economy — in other words ecology. Safety and mechanical serviceability are guaranteed by traditional mechanical design with statistical and dynamics methods. Controlled technical serviceability throughout the target service life is guaranteed by durability design. Health is protected by methods of building physics, including hygrothermal physical and chemical methods. Design for recycling is a special area with its own considerations and methods. The selection of final solutions between alternative structural ideas, materials and products can be done by applying the methods of multiple requirements decision-making. Modular product and performance systematics can be applied at several of the design phases.

The methodology of integrated life cycle design can be used at the design of individual buildings or other structural facilities, as well as in the development of new materials and structures or structural systems.

Many research results exist which allow the introduction of new design methods into praxis. However, new basic knowledge is needed especially in regard to hygrothermal behaviour, durability and service life of materials and structures in varying environments. This knowledge will then have to be put into practice through standards and practical guides. The creation of new types of materials and structures in which the properties can be tailored to each specific need is of vital importance.

Before integrated life cycle design can be introduced into practice, many new guides and standards will be needed. Some such guidelines already exist as international and national standards, but do not yet suffice. Extensive education will also be needed to give practising engineers the required skills in the expanded design process and its methods.
Keywords: Design, life cycle, requirements, environment, integrated design, ecology, service life, durability.

1. Introduction

Our societies are living in a time of rapid change in which old values and traditions are being increasingly challenged Clearly recognisable in the building sector are pivotal changes in the goals and requirements of construction. The main trend is an increase in the basic requirements of buildings and building facilities /1/. Traditionally the four groups of requirements have been functionality, resistance, aesthetics and economy. To these we now to add ecology and general sustainability, and increasingly health aspects.

Sustainability must always be treated according to the life cycle principle — in other words with the application of life cycle methodology to design, manufacture, construction, maintenance, and the management of building projects, companies and other organisations in building. Referring to Fig. 1 we could give a technical definition for sustainable building as follows (Sarja, 1997) /2/: "Sustainable building is a technology and practice which meets the multiple requirements of the people and society in an optimal way during the life cycle of the building facility."

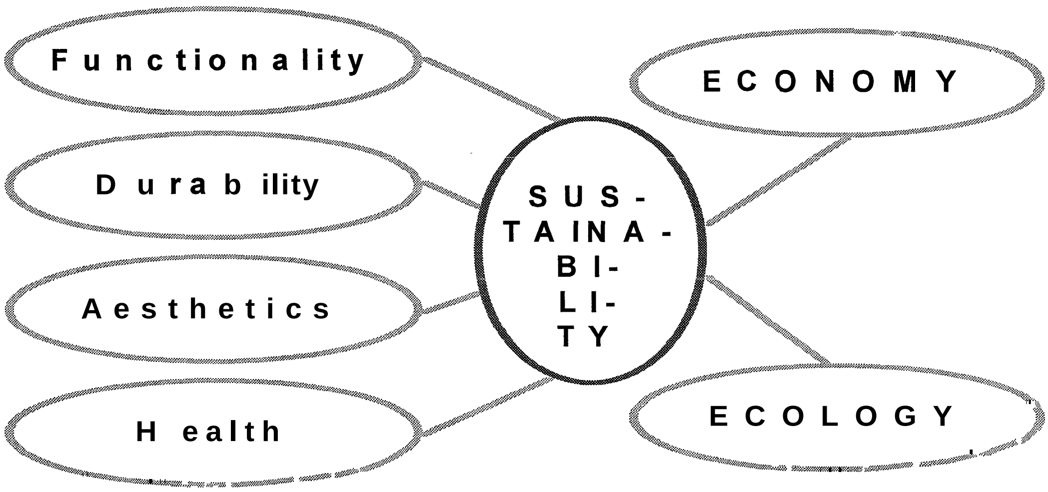

Fig. 1. Multiple requirements for sustainable buildings /2, 8/.

2. Principles of integrated life cycle design

2.1 Interpretation of requirements in economical and technical terms

Sustainability is related to ecology and economy. The ecological aspects include the quantitative goals regarding the consumption of non-renewable natural resources, the production of pollutants into air, soil and water and the qualitative goals regarding non-calculative effects like biodiversity and noise. Ecology can be interpreted as the economy of the nature (Sarja, 1995) /3, 4/. The term gives us a quite concrete starting point for the application of this aspect to materials and structural engineering and it can be concretised in the life cycle methodology in design, manufacturing, construction and management.

Through the principle of sustainability, resistance design will be expanded into durability design to include time as a new dimension in the design calculations. Health aspects are generally related to the control of moisture and thermal conditions and to special subjects like hazardous emissions from materials.

Design for recycling is an important tool for saving natural non-renewable resources and for reducing the environmental impact.

2.2 General framework and design process

The overall scheme of the integrated structural design (fig.2) includes the following main phases of the design process (fig.3): Analysis of the actual requirements, interpretation of the requirements into technical performance specifications of structures, creation of alternative structural solutions, life cycle analysis and preliminary optimisation of the alternatives, selection of the optimal solution between the alternatives, and finally the detailed design of the selected structural system.

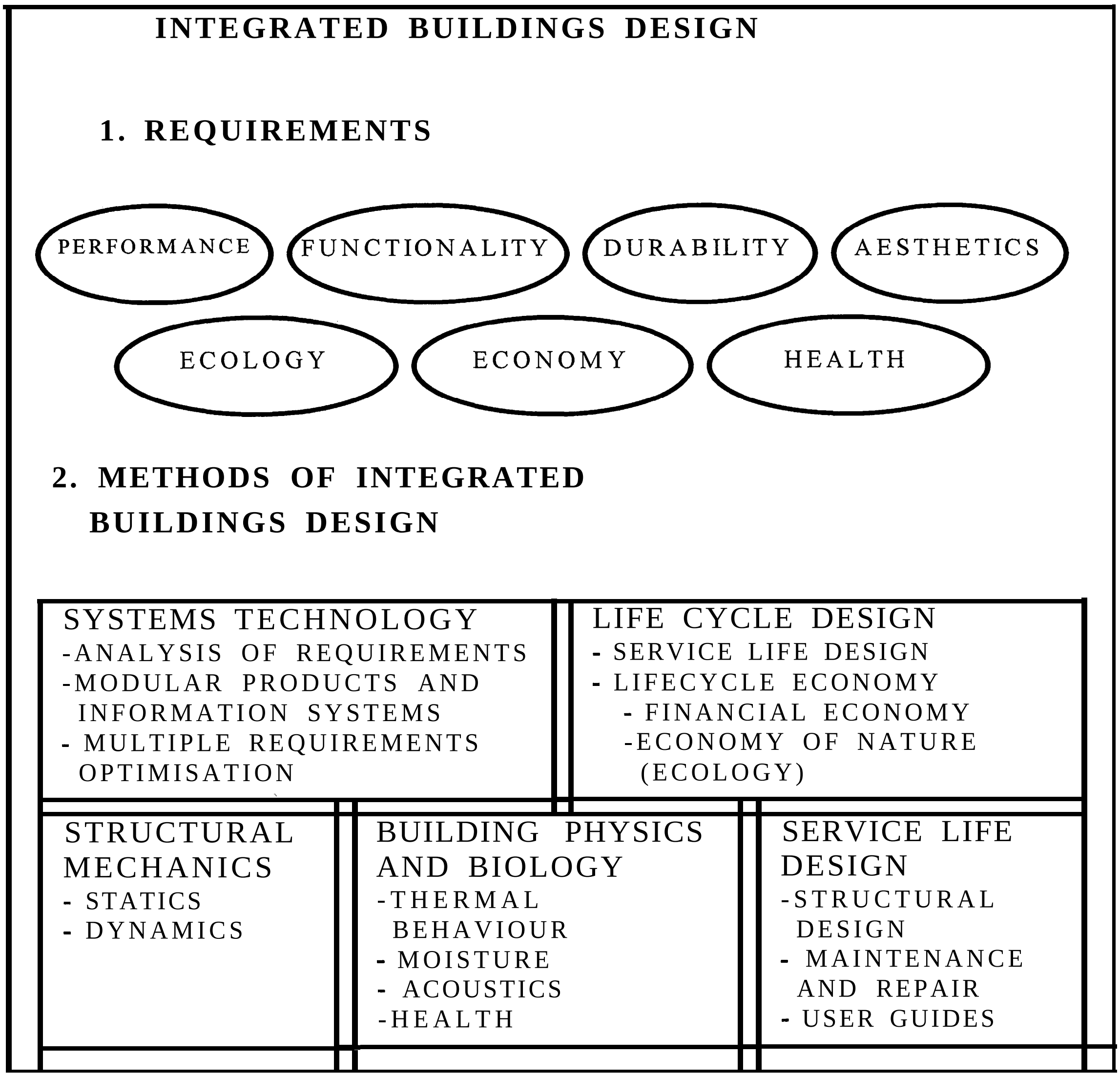

Fig. 2. Framework of integrated structural design (Sarja, 1996) /2, 6, 7/.

The conceptual, creative design phase is very decisive for utilising the potential benefits of the integrated life cycle design process effectively. This is the phase at which the design is done at system level. Modular systematics help rational design, because the structural system typically has different parts, here called modules, with different requirements e.g. regarding durability and service life requirements.

Controlled and rational decision making when optimising between multiple requirements with different metrics is possible through the application of systematics of multiple requirements decision making. All these aspects are widening the scope of structural design and construction to the extent that the entire working processes must be re-engineered. Close co-operation with clients and architects is therefore needed. In design, we can start to establish a new design process, or so-called integrated structural design, which is scheduled and described below.

ANALYSIS OF FUNCTIONAL REQUIREMENTS
SPECIFICATION OF TECHNICAL PERFORMANCE REQUIREMENTS
CREATION AND SKETCHING OF ALTERNATIVE STRUCTURAL SYSTEMS

ENVIRONMENTAL DESIGN

- **analysis of the environmental expenditures**
- **checking environmental requirements and criteria**
- **development of the structural system**
- **renewed analysis**

MULTIPLE CRITERIA DECISION MAKING AND SELECTION OF THE OPTIMAL ALTERNATIVE

- **definition of performance parameters**
- **transfer of values of environmental expenditures from the analysis results**
- **definition of the weighting factors for performance and expenditure factors**
- **multiple criteria selection between the design alternatives**

MECHANICAL DESIGN PHYSICAL DESIGN DURABILITY DESIGN

FINAL INTEGRATING DETAILED DESIGN

Fig.3. The process of integrated structural design (Sarja, 1995) /4, 5, 7/.

2.3 Methods of the integrated life cycle design

The key issues from an environmental viewpoint are the life cycle monetary and natural economy, and the service life design.

The conceptual, creative design phase plays a decisive role in the effective exploitation of the potential benefits of integrated design. At that stage, the design works on a system level. Modular systematics greatly help rational design, because the technical systems typically comprise different parts, here called modules, each with different requirements as to e.g. durability and service life.

For life cycle design the analysis and design has expanded to two economical levels: monetary economy and ecology, which means the economy of nature /3, 4, 7/. Life cycle expenses are calculated at present value or in yearly costs by deducting the expenses of manufacture, construction, maintenance, repair, changes, modernisation, reuse, recycling and disposal. Monetary expenses are treated as usual in current value calculations. Those relating to nature are the use of non-renewable natural resources, the emission of pollutants into air, water or soil, and global warming. These impacts dictate the environmental profiles of the structural and building service systems. The environmental impact profile generally includes the consumption of globally and locally critical raw materials like energy and water and the production of CO_2, CO, SO_2, NO,, dust, solid wastes and noise. The aim is to limit and minimise natural expenses below the allowed values. Some ecological impacts, like noise and reduction of biodiversity, cannot be calculated, but must be considered separately during the decision-making process.

Safety and mechanical serviceability is guaranteed through traditional mechanical design with the use of statics and dynamics. Controlled technical serviceability throughout the target service life is guaranteed by durability design /9/. Health is protected through building physics including hygrothermal physical and chemical methods. The final choice between alternative structural ideas, materials and products can be made by applying the methods of multiple requirements decision-making.

The active reduction of wastes in construction and renovation is possible through designing for selective dismantling in renovation and for recycling of new structural systems, components and materials.

Currently, monetary and natural economies may stand in contradiction to each other because of e.g. differences in pricing and taxes between work and natural resources. Such instances lead to valuation problems, which must be resolved by the clients using their defined valuation within the framework of a society’s norms. Besides the calculated expenses are factors which cannot be numerically defined, such as the impact of construction on biodiversity and noise emissions. These must be evaluated and valuated separately by society’s general rules for individual design cases.

Introducing integrated design principles into practical design is quite an extensive process. Not only is the work of structural engineers changing, but the form of their co-operation with other partners of construction and use will have to be developed — particularly if the structural engineers’ expertise is to be maximally effective at the decisive creative and conceptual phases of design. This kind of co-operation also helps clients realise the benefits of investing slightly more in the structural design.

2.4 Factors of sustainability

Much sustainability analysis and assessment work has been done during the last decade. In most cases life cycle methodology has been applied. The results of comparisons regarding all types of main sustainability requirements, generally speaking, lead to the conclusion that differences between different materials and structural solutions of the construction phase are quite small. On the contrary, quite large differences can be found between life cycle sustainability factors of existing entire buildings or other facilities. The differences are caused by differences in the basic factors of sustainability, which are flexibility in design, changeability during use, durability by comparison with the design service life, and the recyclability of components which have quite a short service life. In order to focus on these factors it is necessary take a separate look at the different types of facilities.

In buildings the energy consumption is economically important and dictates mostly the environmental properties in the life cycle, the differences in environmental economy between different structural systems being otherwise quite small. For this reason, besides well-controlled heating, ventilation and heat recovery, the thermal insulation of the envelope is important. The bearing frame is the most massive and long lasting part of the building, and the durability and flexibility in view of functional changes, spaces and service systems are very important. The envelope must be durable and, as mentioned above, have an effective thermal insulation and a safe static and hygrothermal behaviour. The internal walls have a more moderate length of service life, but they have a requirement of coping with relatively high degrees of change, and must therefore possess good changeability and recyclability. An additional property of an environmentally effective structural system is a good and flexible compatibility with the building service system, as the latter is the most frequently changed part of the building. In the production phase it is important to ensure the effective recycling of the production wastes in factories and on site. Finally, the requirement is to recycle the components and materials after demolition.

Engineering structures like bridges, dams, towers, cooling towers etc. often are very massive and their target service life is long. Therefore environmental efficiency is tied to selection of environmentally friendly local raw materials, high durability and easy maintainability of the structures during use, minimising and recycling of construction wastes, and finally recycling of the components and materials after demolition. Some parts of the engineering structures like water proofing membranes and railings have a short or moderate service life and therefore the aspects of easy reassemble and recycling are most important.

All factors mentioned above are related to the properties connected to the function and performance of the facilities. We know that the decisive factor in our society is financial economy. The budget must always stay within the agreed limits and plays a major role when decisions between design alternatives are made.

Conclusively, the most important sustainability factors in performance for structures with long target service life can therefore generally be defined as flexibility towards functional changes of the facility and high durability, while in the case of the structures with moderate or short target service life changeability and recycleability are dominating. The competitiveness in sustainability between materials and structures focuses on the question of which materials and structures are able to be produced, designed and manufactured with skill and at the same cost, for the best sustainability of the building facility.

2.5 Modular systematics in design

In advanced building we can apply so-called modular systematics /10/. Modulation involves division of the whole into sub-entities, which to a significant extent are compatible and independent. Compatibility makes it possible to use interchangeable products and designs that can be joined together according to connection rules to form a functional whole of the building or another structural system. Typical modules of a building are the bearing frame, facades, roofing system, partition walls and building service systems.

Modular product systematics is firmly tied to the performance systematics of the building. For example, the main performance requirements of floors can be classified as follows:

1. Mechanical requirements, including
   - static load bearing capacity,
   - serviceability behaviour: deflection limits, cracking limits and damping of vibrations
2. Physical requirements, including
   - air tightness
   - acoustics: airborne sound insulation, impact sound insulation, emission
   - moisture tightness (in wet parts of the floor)
   - thermal insulation between cold and warm spaces
   - fire resistance and fire insulation
3. Flexible compatibility with connecting structures and installations
   - partitions
   - services: piping, wiring, heating and ventilation installations
4. Other requirements: buildability, changeability during use, easy demolition, reuse, recycling and wasting.

2.6 Recycling aspects in design

The consumption of building materials can be considerably limited with effective recycling and use of by-products like blast furnace slag, fly ash and recycled concrete. The components of the environmental profile of the basic materials already include the recycling efficiency, which means the environmental expenses in recycling. It is important to realise that the recycling possibilities of building components, modules and even technical systems must be reconsidered in connection with design. The higher the hierarchical level of recycling, the higher also the ecological and economical efficiency of recycling /3, 7/.

3. Research needs

Concerning materials and structures, new basic knowledge will be needed especially regarding hygrothermal behaviour, durability and service life of materials and structures in varying environments. Structural design methods will have to be developed that are capable of life cycle design, multiple analysis decision-making and optimisation. Recycling design and technology demand further research in design systematics, recycling materials and structural engineering. The knowledge obtained will have to be put into practice through standards and practical guides. The creation of new types of materials and structures, in which the properties can be tailored separately for each specific need, is of vital importance. Both strong and soft solutions must be sought, depending on the specific life cycle requirements. New creative innovations for applications of by-products and recycling materials from industry and general consumption are still needed..

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References

1. Sarja, Asko, Environmental Design Methods in Materials and StructuralEngineering. CIB Information, Nr. 4/96. Rotterdam, October/November 1996. pp. 23 - 25.
2. Sarja, Asko, A vision of sustainable materials and structural engineering. In: Selected research studies from Scandinavia. Report TVBM-3078. Lund University, Lund Institute of Technology. Lund, Sweden, 1997. Pp. 153-l 63.
3. Sarja, Asko. Development towards the ecological and recyclable building materials technology. Second International Conference on Materials Engineering for Resources, Akita, October 19-22, 1994, pp. 139 - 145. Research Institute of Natural Resources attached to Mining College, Akita University, Japan.
4. Sarja, Asko, Methods and methodology for the environmental design of structures. RILEM Workshop on environmental aspects of building materials and structures. Technical Research Centre of Finland, Espoo 1995. 5 p.
5. Sarj a, A., Integrated structural design. Nordic Concrete Research, Proceedings: Nordic Concrete Research Meeting, Espoo, Finland, pp. 218 - 219. Publisher: Norsk Betongforening, Postboks 23 12, N-020 1 Oslo, Norway.
6. Sarja, Asko, Some Principles of Integrated Structural Design. Structural Engineering International (SEI), Nr. 1/1997. IABSE, Zurich. pp. 59-60.
7. Sarja, Asko, Framework and methods of life cycle design of buildings. Symposium; Recovery, Recycling, Reintegration, R´97, Geneva, Switzerland, February 4-7, 1997. EMPA, 1997, Volume VI, pp. 100-l 05.
8. Sarja, Asko, Prefabrication in relation to sustainable building. Prefabrication - facing the new century. International symposium, 1-3 October, 1997. Concrete Association of Finland, Helsinki, Finland, pp. 143-146
9. Sarja, Asko & Vesikari, Erkki (Editors), Durability design of concrete structures. RILEM Report Series 14. E&FN Spon, Chapman & Hall, 1996. pp.
10. Sarja, Asko & Hannus, Matti, Modular Systematics for the Industrialized Building. VTT Publications 238, Technical Research Centre of Finland, Espoo 1995,216 p.

Analytical comparison of buildings in terms of environmental impact criteria

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Abstract
The basic resource and waste utilization strategies for a sustainable environment in the context of buildings enshrine many exo- and endogenous factors influential to design. These factors implicate or embed the attributes of buildings for comparison. In order to quantify the effects of these building attributes on the environmental quality various parameters on energy and mass flows are designated as medium or effect oriented criteria, indicative of the performance of one or more attributes. The flows manifest cumulative ecological consequences at local, regional and eventually global scales. Some of the criteria pertain to more than one building attribute which may also be appraised by more than one criterion. The interrelated domains involved are the projects, elements and life-cycle of the conceptual building model. An algorithmic comparative method is proposed here for the environmental impact analysis of any one or all of these above. The main consecutive steps of the method are Environmental data acquisition, Synthesis and Result presentation. Any two of the four domains can be explored by each implementation of the method. The evaluation process of each step incorporates value normalization and aggregation augmented by the other supplementary statistical parameters of standard deviation and coefficient of variation beside the average for obtaining a single overall comparative indicator. If all combinations are to be explored than evaluation procedure proliferates and at each step several processes are executed. Alternatively, the procedure is repeated for each pair of the domains. The acquired data is evaluated in two consecutive stages by different sets of criteria. These stages employ the same procedure, but environmental and statistical criteria are substituted respectively. Each stage comprises the following steps: Selection of relevant criteria, their utility functions and weights, Calculation of absolute values of criteria, Conversion to weighted normalized (relative) values. Thus a more comprehensive representation of the environmental performance of each domain component becomes possible.
Keywords: Building performance evaluation, Environmental impact criteria, Life cycle assessment.

1 Introduction

Concerns on the total environmental quality become gradually more significant as natural resources, which are essential for the survival of mankind and his habitat, are being depleted at the current rate. The primary aim is to alleviate the adverse effects of artificial processes on the natural environment for restoring the ecological balance.

In the context of buildings, as a component of the artificial environment, the three interrelated domains involved are the projects, elements and phases of the conceptual building model. These are required to be examined in terms of medium and effect oriented impact criteria based on mass and energy flows which manifest cumulative effects at local, regional and global scales. Some criteria pertain to more than one building attribute which may also be evaluated by more than one criterion.

A brief review of some recent relevant works on this subject is presented as follows. Haagenrud and Henriksen review corrosion assessment studies for materials in the context of built environment degradation [l]. The mechanisms of the latter and the dose response functions are considered in terms of the concepts of critical loads and acceptable corrosion rates. Beccali and Cellura describe the comparative evaluation of energy and environmental performances of constructional alternatives as prescribed by the Electre methodology incorporating surclassment functions [2]. Le Teno and Chevalier modify the conventional life cycle assessment model to obtain an environmental quality evaluation model by redefining system boundaries on the basis of the practitioner's design constraints and goals and introducing environmental quality as an additional attribute [3]. Luetzkendorf describes a building product information system incorporating environmental, technical, health and cost data [4]. Weibel presents the cumulative normalized environmental effects of building materials to allow comparative appraisal [5]. Kohler and Klingele apply the life cycle assessment model in terms of energy and mass flow to the building as an object consisting of elements and phases [6]. Klingele and Kohler investigate the effects of decisions on design alternatives at various project phases on environmental performance in conjunction with a databank [7]. Adalberth presents a method to aggregate the embodied total energy consumption due to material manufacture, waste, replacement and transportation during the successive phases of building [8]. Aygun explores the effect of geometry on the energy performance of building blocks as expressed in terms of design parameters [9].

2 Conceptual building model

For the purpose of representing the building object as a physical entity, in the context of environmental impact appraisal, four distinct domains are prescribed here: Project, Elements, Life cycle and Criteria. These comprise groups of related attributes or components, whether physical or notional, describing various aspects of the building. While the first three, as the independent variables, are assigned nominal values exclusively, the last, as the dependent variable, involves values in ordinal, interval and ratio scales. The term performance refers hereafter to the environmental performance.

The model can be abstracted as a triangulated diagram with nodes representing domains, described below as synopses to examine their effects on the eco-balance, and edges representing relationships (Figure 1).

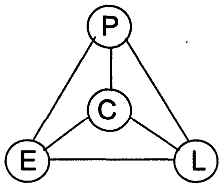

Figure 1: Nodal Representation of Domains

2.1 Project domain

Before taking any decision to proceed with a new building project the primary consideration should be whether this is absolutely essential. The overall properties are specified of those buildings to be compared in terms of their ecological implications.

Location: Rural, urban, suburban. Orientation, exposure, topography. Type: Existing, prospective. Historic, refurbishable. Form: Low or high rise. Compact, slender, irregular. Function: Residential, public, industrial, commercial. Chemical processes. Intensity, duration.

2.2 Element domain

Every building consists of functional elements which are reviewed in 3 categories and contain many physical components with different influences on the environment.

Infrastructure: Roads, paved areas, pipes, cables. Substructure: Excavations, foundations, basements. Superstructure: External, internal. Floors, walls (opaque and transparent parts), roofs. Configuration of elements inclusive of finishes and fit-out. Structure: Monolithic, loadbearing, frame, studwall, membrane. Services: Supplies of air (ventilation), water (cold/hot), space air conditioning (heating, cooling, humidity control), lighting (natural, artificial), power (electricity). Discharge of drainage (precipitation and waste water), garbage disposal and gas removal. Active, passive or combined systems. Distribution networks of ducts, pipes or cables. Mechanical devices of solar collectors, heat pumps, heat exchangers, energy converters, filters, HVAC. Local or regional services.

2.3 Life-cycle domain

The consecutive phases of the building life-cycle as transient states have different environmental consequences, which are determined by the building attributes. The type and quantity of energy consumed and waste produced affects the performance of each phase each of which also embodies energy due to extraction, transportation (horizontal and vertical) and replacement.

Manufacture: Raw or processed materials. Construction (erection): In-situ, prefabricated. Equipment. Preservation of natural assets. Occupation: User behaviour patterns. Efficiency devices of optimal start controls, sensors, thermo- and humistats. Maintenance and Repair: Durability(economic service life). Replacement. Chemicals. Refurbishment (renovation): Recycle, reuse. Demolition: Recycle, reuse.

2.4 Criteria domain

The basic resource and waste utilization strategies for a sustainable environment in the context of buildings are listed here as: Restriction on resources, Reduction of waste, Implementation of passive systems, Exploitation of renewable resources, Reuse or recycle of resource and waste.

These strategies enshrine many exo- and endogenous factors pertaining to the design of buildings: Orientation and location, Geometric form, Disposition of internal spaces, Primary function, Occupation pattern, Mechanical HVAC systems, Air infiltration and ventilation, Attributes of the external envelope, Waste recycle, Maintenance.

These factors implicate or embed the attributes of buildings in question. In order to quantify the effects of these building attributes on the environmental quality various parameters on energy and mass flow are designated as effect or medium oriented criteria which indicate the performance of one or more attributes. Some criteria may pertain to more than one attribute, which may also be evaluated by more than one criteria. The type of numerical criteria can be quantity, ratio or coefficient. Within the scope of this work the medium oriented criteria in the form of energy and mass are reviewed here in the two groups of Resources and Emissions. The former comprises those supplies obtained from the environment and the latter discharges from the building. The two sets of criteria below are non-exhaustive. Either one of them may be adopted for evaluation.

Medium-oriented Criteria

- Resources
  - Energy (embodied)
    (primary, delivered, useful)
    - Fuel
      (Renewable, Non-renewable)
    - Electricity
  - Air
  - Water
  - Materials
    - Natural (Organic, Inorganic)
    - Synthetic
- Emissions (Solid, Liquid, Gas)
  - Toxic/pollutant
  - Biodegradable
  - Non-toxic

Effect-oriented Criteria [10]

- Acidification
- Aquatic and terrestrial ecotoxicity
- Bio- and abiotic resource depletion
- Global warming
- Human toxicity
- Noise
- Nutrification
- Odor
- Ozone depletion
- Photochemical oxydant creation
- Waste heat

3 Method description

The main consecutive steps of the method are Environmental Data Acquisition, Synthesis and Result Presentation (Figure 2). Any two of the four domains can be explored by each implementation of the method. The evaluation process of each step incorporates value standardization and aggregation augmented by multiple statistical parameters. If all combinations are to be explored than evaluation procedure proliferates and at each step several processes are executed. Alternatively, the procedure is repeated for each pair of the domains.

Step 1 (Data Acquisition): The value of each criterion for all domains in a 3-dimensional matrix or a series of tables for all building alternatives.

Step 2 (Data Synthesis): Subsequently the individual values are aggregated, supplemented by multiple statistical criteria, to obtain average criterion values for the corresponding domains. For aggregating values with different units of measurement a normalization process is used as described later.

Step 3.1 (Inter-domain Results): The values from the previous step are aggregated for the pair of domains in question and presented in tabular form.

Step 3.2 (Intra-domain Results): The values yielded above are further aggregated in rows or columns, as appropriate, to obtain the average performance for each component of that domain. Finally, the components can be ranked for each domain.

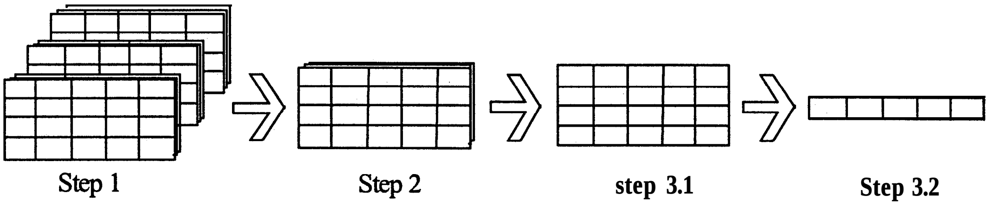

Figure 2: The Method Sequence

Whenever aggregation is to be carried out across different criteria at each step the values are standardized through interpolation prior to aggregation. Additionally, performance functions and criteria weights are applied. Beside the average, the process takes into account the supplementary statistical parameters of standard deviation and coefficient of variation for obtaining a single overall performance indicator. Consequently the initial average absolute criterion values are converted to absolute performance values and then to weighted relative statistical performance values. Thus a more comprehensive representation of the environmental quality of each domain value becomes possible. The acquired data is evaluated in two parts by different sets of criteria. These parts employ the same procedure, but environmental and statistical criteria are substituted respectively. The steps of each part are described below. The numbers in parentheses refer to the step in the flowchart (Figure 3).

3.1 Environmental criteria evaluation (B1)

1 Environmental criterion functions (1.1): Express the relevant environmental criteria as functions of exogenous and endogenous independent design variables for achieving the preset objectives

2 Environmental performance functions (2.1): Establish the appropriate environmental performance function for each criterion in terms of that criterion. This process can be concurrent with 2.2 as well as with 2.3. and 2.4.

3 Environmental criterion weights (2.2): Rank-order and draw hierarchical tree for objectives in order to set the relative weights of the environmental criteria with

respect to their contribution to achieve the objectives. This process can be concurrent with 2.4. as well as with 2.1. and 2.2. of the previous part.

4 Environmental criterion values (3): Calculate the environmental criterion values through that function for each domain component.

5 Elimination of building alternatives (4): Identify those eligible alternatives which satisfy all mandatory limits of criteria stipulated by standards, codes and regulations, directives, etc. or which attain above-average values for all criteria.

6 Absolute performance values (5): Calculate the absolute performance values through that functions of each criterion for the domain component.

7 Weighted relative performance values (6): Normalize environmental performance values by converting them from absolute to relative through linear or non-linear interpolation as required and apply the weights.

3.2 Statistical criteria evaluation (B2)

1 Statistical criterion functions (1.2): Select the suitable statistical criterion functions or approve defaults, i.e. standard deviation and coefficient of variation.

2 Statistical performance functions (2.3): Establish the performance functions in terms of statistical criteria or approve the defaults, i.e. linear function.

3 Statistical criterion weights (2.4): Set the statistical criterion weights to reflect the environmental objectives. The default weights are all equal.

4 Statistical criteria values (7): Calculate the statistical criterion values through that function for each alternative.

5 Absolute Statistical Performance Values (8): Calculate the absolute statistical performance values through that function of each criterion for the alternatives.

6 Weighted relative statistical performance values (9): Normalize statistical performance values by converting them from absolute to relative through linear interpolation and apply the weights.

7 Ranked shortlist (10): Prepare a ranked shortlist of satisfactory alternatives which attain above-average pre-normalized values for all statistical criteria.

8 Correlation between variables and ranks (11): Ascertain any effects of design variables on the rank of alternatives by correlation.

4 Discussion

The results in the penultimate step of the evaluation procedure are tabulated for any combinatorial pair of the four domains, namely project, elements, phases and criteria so as to compare the performances of their components. Consequently, six different tables can be obtained, each of which exploring the effect of one domain on an other. Furthermore the cumulative effects of the element and phase domains at different hierarchical levels can be investigated.

In the ultimate step of the procedure the components of one domain can be ranked in order of their overall performance , allowing the most satisfactory ones to be identified. For example, that building design alternative with the highest performance in any given set can be selected for further development. As for the other domains, those elements, phases and criteria relatively efficient or deficient in environmental quality can be ascertained.

5 Conclusions

As apparent from the preceeding description the proposed method of environmental appraisal relies on comprehensive acquisition and compilation of accurate data for all domains as a prerequisite. In view of the diversity of the various criteria involved in the process the practical constraints of obtaining this data in standard format and the absence of adequate database facilities inhibit as yet any effective large-scale application of this and other methods involving quantitative analysis. In this respect the direct use of ordinal values for the impact criteria may expedite the application process.

At present there is sufficient technical knowledge available for achieving improvement in environmental quality. However the main task remains to be the implementation of this knowledge in actual practice according to guidelines [11] and the immediate enforcement of current standards regulating environmental management and life cycle assessment [12].

Resolute and collective support of all efforts by scientific, professional, industrial, legislative organizations as well as individuals will contribute towards more sustainable natural and artificial environments through a balanced interaction.

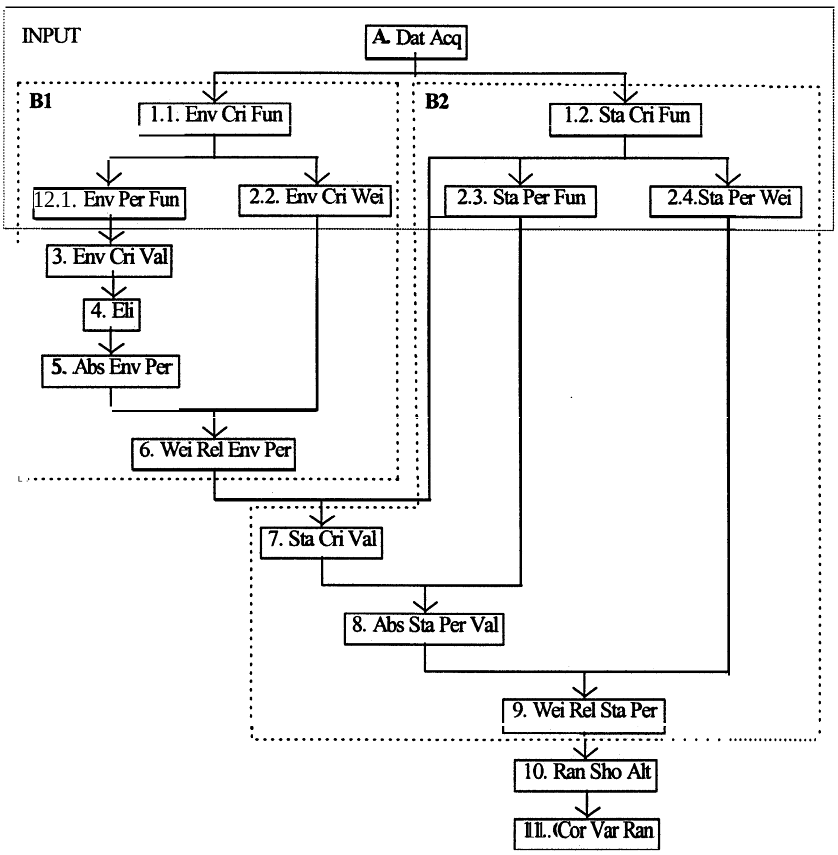

Figure 3: Flowchart of the Environmental Evaluation Procedure

References

1. Haagenrud, S.E., Henriksen, J.F. (1996) Degradation of Built Environment-Review of Cost Assessment Model and Dose-Response Functions, *Durability of Building Materials and Components* 7, Ed. Sjöström, pp.8596, E.& F.N. Spon, London.
2. Beccali, G., Cellura, M. (1996) Life Cycle Assessment of Building Materials: A Comparison by Electre Methodology, *Durability of Building Materials and Components* 7, Ed. Sjöström, pp.813-823, E.& F.N. Spon, London.
3. Le Teno, J.F., Chevalier, J.L. (1996) A Tool for Improving the Environmental Quality of Building Products, *Durability of Building Materials and Components 7,* Ed. Sjöström, pp.839-847, E.& F.N. Spon, London.
4. Luetzkendorf, T.(1996) Ökologische Bewertung von Baustoffen, Bauteilen und Gebaeuden, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings,* pp.201-206, Vienna, Austria.
5. Weibel, T. (1996) Oekoinvantare und Wirkungsbilanzen von Baumaterialien, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings,* pp.207-2 12, Vienna, Austria.
6. Kohler, N., Klingele, M. (1996) Simulation von Energie und Stoffflüssen von Gebaeuden waerend ihrer Lebensdauer, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings,* pp.21 3-218, Vienna, Austria.
7. Klingele, M., Kohler, N. (1996) Berechnung von Energiebedarf, Baukosten und Umweltbelastung in frühen Projektphasen, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings,* pp.21 9-224, Vienna, Austria.
8. Adalberth, K. (1997) Energy Use during the Life Cycle of Buildings: A Method, *Building and Environment,* Elsevier Science Ltd., Vo1.32, No.4, pp.3 17-320.
9. Aygün, M. (1996) Building Geometry in the Context of Energy Performance, *International Symposium of CIB W67: Energy and Mass Flow in the Lifecycle of Buildings,* pp.3 1-36, Vienna, Austria.

1 O.Heijungs, R., Guinee, J., Huppes, *G.* et al. (1992) *Environmental Life Cycle Assessment of Products,* Guide, Centre of Enviromental Science, Leiden, Holland.

11 .Bund Deutscher Architekten (1994) *Umwelt-Leitfaden fur Architekten,* Ernst & Sohn, Berlin, Germany.

12.ISO 14001: 1996, IS0 14004: 1996 (Environmental management systems), IS0 14010:1996, IS0 14011:1996, IS0 14012:1996 (Environmental auditing), ISO/DIS 14020, ISO/DIS 1402 1 (Environmental labels and declarations), IS0 14040:1997, ISO/DIS 14041, ISO/DIS 14050 (Life cycle assessment).

Environmental relevant product information in the Dutch building industry

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The importance of environmental relevant product information as a tool to achieve product improvement is broadly recognised by the building industry, designers, commissioners and governments. It is also recognised that the information provided by the building industry must be based on a reliable standard method presented in a standard format.

The Dutch building industry has recently started the ‘MRPI-project’ (MRPI is the abbreviation of environmental relevant product information) in which a format is developed for the harmonisation, on the international consensus on Life-cycle assessment (LCA) and is adjusted to the specific needs of the building industry. Guidelines for LCA practice and communication of the results are developed.

The information is useful for several partners. Governments use this information for policies regarding sustainable building, researchers dealing with LCA in the building industry are supplied with well documented and reliable inputs for their databases and the building industry can focus on real product improvement rather than dissipating their energy in disputes about methodology, assumptions and reliability.

In this contribution the format and use of the format in the building industry is explained. The importance for international discussion as well as international projects dealing with this subject is mentioned.

Keywords: building industry, environment, LCA, MRPI, product information

1. Introduction

In the Netherlands the Ministry of Housing, Physical planning and Health (VROM) has developed a policy plan for sustainable building in 1995 [1]. One of the aims of this policy plan is the introduction of reliable standardised and quantitative information of building materials, products and elements. This information should be based on an integral life cycle approach. For this purpose the most appropriate and widely used tool is the Life cycle assessment, the LCA methodology. This aim is communicated, constructed and implemented in co-operation with the Environmental Council for the Construction Industry, the MBB, in which the building industry is organised. In 1997 the succeeding second policy plan for sustainable building strengthens the importance of environmental relevant product information for building materials [2].
As a result of this strengthened importance the building industry in the Netherlands, organised in the Dutch council of suppliers of the building sector (NVTB) has committed itself to make this information publicly available.
For this purpose in the first half of 1997 the NVTB has started the 'MRPI' project. MRPI is the abbreviation of environmental relevant product information.

2. The MRPI project

In 1995 the NVTB committed herself to provide reliable quantitative environmental relevant product information for all building materials applied in the Netherlands. The NVTB recognised that LCA is the most appropriate tool for this purpose. The choice for LCA is based on the policies from the national government and the MBB. Several producers have already carried out LCAs for their products. From experiences of these LCAs the NVTB learned that harmonisation of LCA practice is of vital importance when LCA results have to be compatible. The NVTB aims at a broad participation of it's members. Therefore the NVTB started the MRPI project in which interaction with it's members is the basis for this harmonisation.
The MRPI project aims at providing environmental relevant product information to several users in society. For this purpose it is agreed upon that a uniform format must be developed. This format must comprise guidelines to construct and present MRPI. MRPI is defined as *verified* information on environmental aspects of a building material, product or element that is constructed on the *initiative* of *the producer*, that can be used for communication to specific target groups. MRPI will be verified. This verification is still to be outlined. IS0 describes verification as a 'peer review', within MRPI it is thought of in terms of environmental declaration with a MRPI-label.

Another important aspect of MRPI is that it is constructed on the initiative of the producer. The MRPI shall therefore reflect, with the best possible data, at least the processes, which actually take place at the production site of this producer.

In the MRPI-project representatives of all different sectors in the building industry participate in three Working groups. In Figure 1 you see that the project is split up in three phases and a Working Group Data / format, Communication and Verification.. In this paper we will focus on the work of the Working Group Data / format.

Working Group Data / Format	**Working Group Communication**	**Working Group Verification**
Concept manual for MRPI Pilot projects Final manual for MRPI	Communication plan Format for presentation and communication of MRPI	Development of a verification structure

Figure 1. The Working groups and tasks of the MRPI project

Task one of Working Group Data / format is the development of guidelines to construct MRPI. Since MRPI is based on LCA the guidelines are based on the draft IS0 14040-series and the international developments from SETAC and SPOLD. The general guidelines are adapted to the specific needs and characteristics of the building industry.
The manual leads producers through the most important points of attention and choices to be made within LCA. Some choices are fixed based on consensus in the Working Group. For the elaboration of other choices checklists are constructed. In several cases the possibilities are indicated.
For example the target group for communication of MRPI must be chosen. The choice of the target group can differ from the National Package Sustainable Building from the Dutch national government to architects or researchers. All target groups have their specific needs and goals. Within MRPI it is tried to follow those needs as far as possible. This can imply different elaboration of the other choices within LCA.
The important items are listed in Table 1. As you can see some items still need to be discussed and elaborated. One item is the life expectancy of building materials, products and elements. Two directions are discussed, e.g. following the life expectancy guaranteed by the producer, or choosing the empirical life expectance. The discussion tends to the latter.

Table 1. Guidelines for LCA choices within MRPI:

Important items within MRPI	Guideline
• Identification of the goal and target group	Choice indication
• Construction of the functional unit	Checklist
• Description of the product	
Material list	Fixed
Replacements	Choice indication
Maintenance	Fixed
Life expectance	Fixed
• Choice of the system boundaries	
Phases f the life cycle	Checklist
Processes within the life cycle	Checklist
Process tree	Fixed
• Data categories	
Data categories	Fixed
Completeness per category	Fixed
• Allocation	
Multi-output and multi-input allocation	Fixed
System boundary allocation	Not elaborated yet
• Data collection	
For the production site of the initiator of the LCA	Questionnaire
Outside the production site of the initiator	Fixed
Literature data	Fixed
• Data quality	Fixed
• Calculation of the environmental impacts	Fixed

When the manual is followed the LCA results can be calculated and are ready to be presented to the identified target group.

Working Group Communication is working on a format for the presentation of MRPI. It is thought that MRPI can be presented as an A4-form, or environmental declaration. This declaration contains three levels of information:

- MRPI itself
  This are the LCA results expressed in several environmental use classes
- Scope
  The most important choices and system boundaries
- Qualitative information
  Optional space for verifiable producer specific environmental information, e.g. return systems, EMAS, etc.

The second task of Working Group Data / Format are the pilot projects. The members of the NVTB are invited to join these so-called pilots. In the pilots the producers and their associations are invited to screen the concept manual for practicability and to try to fill out the non-fixed items (see table 1). Four product groups are chosen:

- Roofing;
- Walls and floorings;
- Constructions;
- Window frames.

In each product group different producers participate. For example the choice of the functional unit is outlined. According to the experiences of producers, other projects in the Netherlands and the checklist form the concept manual it is tried to form consensus over the functions and quantification of these functions. Related to this functional unit the system boundaries and the material input is filled out. Per product group is determined which maintenance, replacement and life expectance are needed. In the pilots it is tried to find those material inputs and processes that are discriminating between different products which meet the functional demands of the functional unit.
For all items in Table 1 it is tried to seek for possibilities, solutions, or adaptations. The experiences of the pilots are used to adapt the concept manual and to elaborate the verification structure and content.

When the manual is adapted and the most important choices are filled out for the different product groups of the pilots, the producers and associations can start with the construction of MRPI. In order to guarantee that the MRPI provided meets the demands and consensus of the manual a verification structure will be developed. This verification guarantees that the MRPI provided is of the prescribed quality. The elaboration of the verification structure is still under study.
The verification will be based on the balancing the harmonisation principles within the manual with the accomplished choices within MRPI. This is essentially the same as the way that IS0 standards prescribe certain actions. However, the MRPI verification will be broadened and will not necessarily include a complete 'critical review'. For example the verification will be extended to the used data sources. For generic data such as energy generation and transport, but also transport distances, agreements will be made and will be verified. The result of the verification can be a label or certificate.

3. Related projects

The MRPI project goes in front of the developments. Throughout the world there is an explicit need for international discussions in the field of harmonisation of environmental product information. The MRPI project does not stand all by itself. In the Scandinavian countries analogous projects are initiated. For example by the SBI, the Danish Building Research Institute, in Denmark.

4. Conclusions

The MRPI project has two main accomplishments. The first accomplishment is the obtained participation of the producers and associations in the building industry. They have been introduced in LCA practice in with central focussing on discussions and consensus. They have been enabled to learn about the merits and possibilities of LCA for the elaboration and communication of the environmental performances of their products.
The second accomplishment is the obtained harmonisation. Harmonisation is accomplished with the construction of the manual. Also the pilots have contributed to further harmonisation of product group specific items which could not be standardised over the whole building industry. Therefore harmonisation is accomplished not only in LCA practice throughout the building industry but also for the product group specific needs and characteristics.

References

1. VROM (1995) *Plan of action Sustainable Building* Tweede Kamerstuk 24280, 1995, VROM; 95338/a/9-95, 12635/165, VROM, The Hague, ISBN 9039909164 (in Dutch).
2. VROM (1997) *Plan of Action Sustainable Building* 2 Tweede Kamerstuk 25720 nr 1 1997 VROM, 97664/b/11-97, 22804/211, VROM, The Hague (in Dutch).
3. Schuurmans, A and Meijer, J.P.R. (1997) *Concept guidelines for the construction of environmental relevant product information by producers* INTRON report R97 133A, Sittard (in Dutch).
4. Schuurmans, A and Meijer, J.P.R. (1997) *Backgrounds of the guidelines for the construction of environmental relevant product information by producers* INTRON report R97133B, Sittard (in Dutch).

Structuring of data for LCA of buildings

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Abstract
Inventory work for large life-cycle assessment may be facilitated by organizing data according to certain needs. A data structure for life-cycle assessment of Swedish building production is presented in this paper. The basis for the structure is the building component and activity table “the BSAB-system.” A combination of the structure and a computer based analysis software, which is able to support linking of data sets, may be a good support when enforcing system boundaries and performing hot spot analysis.

Keywords: LCA, Building, Environmental Assessment, LCA-data, database, data structure.

1 Introduction

There are several actors in the building industry engaged in different lines of work, but all related to the building. The view of the building as a system, that each actor holds, is not the same throughout the entire industry. The contractor may view the building as a collection of building materials and components that systematically have to be in-stailed to achieve a meaningful structure with agreed upon qualities and functions. On the other hand, the user of the building may see the building as a shelter with thermal, aesthetically and spatial qualities in focus. How the building is viewed, depends on the relationship that the actor has to the building [0], i.e. which life-cycle phase, of the building, the actor is involved in.

When looking at the environmental impact of a building and the process of producing and maintaining the building, the difference in view of the building as a system is important to have in mind, particularly when using Life Cycle Assessment (LCA) [1] as assessment tool. Two case studies [2],[3] which have studied the environmental impact of altogether eleven building frames, have been performed at Technical Environmental Planning, Chalmers University of Technology, Göteborg, Sweden. To be able to perform these studies, a structure for LCA-inventory data was developed. The systems view of the building which this structure supports, is the one of technical designers and the Swedish building material producing industry, hence viewing the building as a production process where flows of matter and energy enters and leaves the building over its life-cycle.

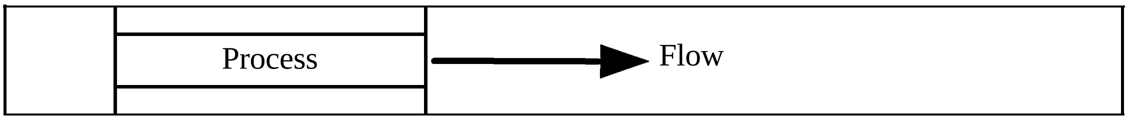
2 The data structure

The data structure had to fulfil1 some primary needs. They all sprang from one of the objects of the case study [2], which was *"...to create a computerized model structure for environmental assessment of frame structures, that may be used as a tool for improvement analysis."*

The structuring of data belongs, from a LCA methodological point of view, to the inventory stage. This stage is in LCA commonly subdivided in three phases: production phase, user phase and the demolition and waste handling phase. The structure primarily handles data in the first phase of the inventory, the production phase.

When contemplating on how to achieve a suitable data structure for a large LCA of a product system, it is important to recognize that there are at least two conceptual models [4] that have to co-operate. First the one of the production system and second the similar of the analysis tool, i.e. the formalized and interpreted model of how global environmental impact occurs. The building production system is a hierarchical system where materials are assembled to products that works with other products to achieve an even more complex product or function. This production system translates into material flows needed to fulfil1 the production phase (cradle to gate) part of the functional unit. As LCA is a flow analysis method, there was basically no conceptual difference between the production system and the tool, which the production system were to be analyzed with. This meant that the basic elements of the LCA (processes and flows, figure 1) worked well as basis for the environmental analysis of the production processes involved in the production phase.

Figure 1 Basic components of the Life Cycle Analysis method.



The data structure were designed to meet three different needs. The first need to met was to organize LCA-data in a pedagogical and “easy to find” fashion that is customary to the building materials industry and technical designers of buildings. The second need was to make the structure expansible and general for data to be added in the future. Finally, the third need to met concerned the organization of LCA-data for production, energy and transport processes in such a way that data would:

- not be redundant,
- be consistent,
- be easy to update,
- easy to use in the inventory process when ever needed,
- be independent of the goal of the study.

Since 1972 a system for describing the building and its components and materials has been a standard in Sweden [5] . The system is called the “BSAB-system” and it consists of two tables: one table classifying the building products by the technical composition of the product, the other table classifying the products by the technical function. For the structure, the latter table was selected as the organizing component to meet the need of information to be customary organized. However, an adapted version of the table was used (figure 2), developed by SBEF (the Swedish Building Contractors Federation). The SBEF-table solely classifies products and activities related to the production process of buildings while the BSAB-system is valid for all types of construction activities.

The need for a general and expansible structure was granted by the product classification table as well. The categories 0 to 2 belongs to activities connected to the building site, categories 3 to 5 belongs to the building envelop and load-bearing structure, while categories 6 to 9 are related to the specific use the building is designed for. Products and activities are being divided in categories by the classification, independent of what building actually is being built, thus making it general and expansible for all types of buildings, components and materials.

The third need to met for the structure is largely connected to the LCA-inventory practice. It holds components of assistance of such LCA issues as keeping system boundaries, and quality of inventory data. The demands that had to be fulfilled were: not be redundant, be consistent, be easy to update, easy to use in the inventory process when ever needed and be independent of the goal of the study.

The redundancy and consistency parts are aspects of the same inventory topic; LCA-data for a specific production process that is used as input-data in the inventory

Figure 2 The Swedish SBEF-table as organizing component of the data structure for LCA-inventory data for the production phase which meets the need of a customary top grid for information.

	·	0	1	2	3	4	5	6	7	8
0	**Demolition**	Project data	dismantling	D. of furnishing, equipment	D. of walls, beams	0ther demolition	D. of elevator, e. shaft	Cut in reinforcement	Construction for. installation	**Temporary** constructic
1	**Ground**	Summary	Clearing, demolition, moving	Excavate, filling	Ground reinforcement, drainage		Cables. culvert, tunnels	Roads, area	Garden	Ground equipment retaining wall
2	**Building substructure**	Summary	-	Excavate, filling	Ground rein f., drainage	Cons. substructure	Culvert, tunnels	-	Foundation ground	Cornpletio
3	**Frame**	Summary	Walls	Columns	Precast	System of beams	Smithwork	Stairs, shafts	co-oper.: roof - frame	Completio
4	**Roof**	**Summary**	**Roof-frame**	**roof-framing completions**	**Roof cover**	base of a roof, gables	Completions for schaks, roof hatch	Plates	Terrace	Cornpletio
5	**Facade**	**Summary**	**Completions**	-	**Facing**		Windows, doors, gates	-	-	Compleetio
6	**Completions /room-formations**	**Summary**	-	**Sub-floor**	**Internal walls**	Ceiling	Internal doors, window sections	Internal stairs	-	Completio
7	**Internal layers/room cornpletions**	Summary	-	Layers - floor, stairs	Layers - walls	Layers - ceiling	Paintwork	White goods	Decoration joinery	Completio
8	**Installations**	Summary	-	Process	-	Sewage, heat	Air **cond.**, ventilation	Electricity	Transport	Control equipment
9	**Joint work**	Summary	-			-			-	

of more complex products several times in the analysis ought not be stored in the data structure more than once. There are several reasons for this. LCA-inventory data for, for example concrete, may be used as input-data for the inventory of more complex concrete products. If the data set[1] for concrete is copied and integrated with the data for the complex products and at a later stage of the inventory work, the data set for concrete was found to be incomplete; then updating the data set becomes a time consuming task that might lead to an inconsistent representation of the environmental impact of the production of concrete if one or more processes has been forgotten. This situation creates data that is redundant which even might be inconsistent for the environmental impact of. the production processes studied. By storing the data set once and link it to the data set of more complex products, redundancy will not occur and the data will be consistent through out the entire structure. By thoroughly considering the system boundaries for the inventory of a production process and comparing the boundaries chosen to the general system boundaries of the study and by storing the data as a single unit[2] data set, the general system boundaries will be kept consistently as well.

By storing data in single units and linking the data set, the procedure of altering the data set (for higher accuracy, sensitivity analysis or improvements of production process etc.) becomes a less time consuming task. Another aspect of storing data in single units is that the data set becomes relatively independent[3] of the goal of the study. The reason being that the data set is not integrated with inventory information for other

[1] A *data set* is a table over the environmental impact that is duo to a specific production process. The table usually contains quantitative data for the energy and raw material use, emissions to air, water and ground per arbitrary pre-defined functional unit.

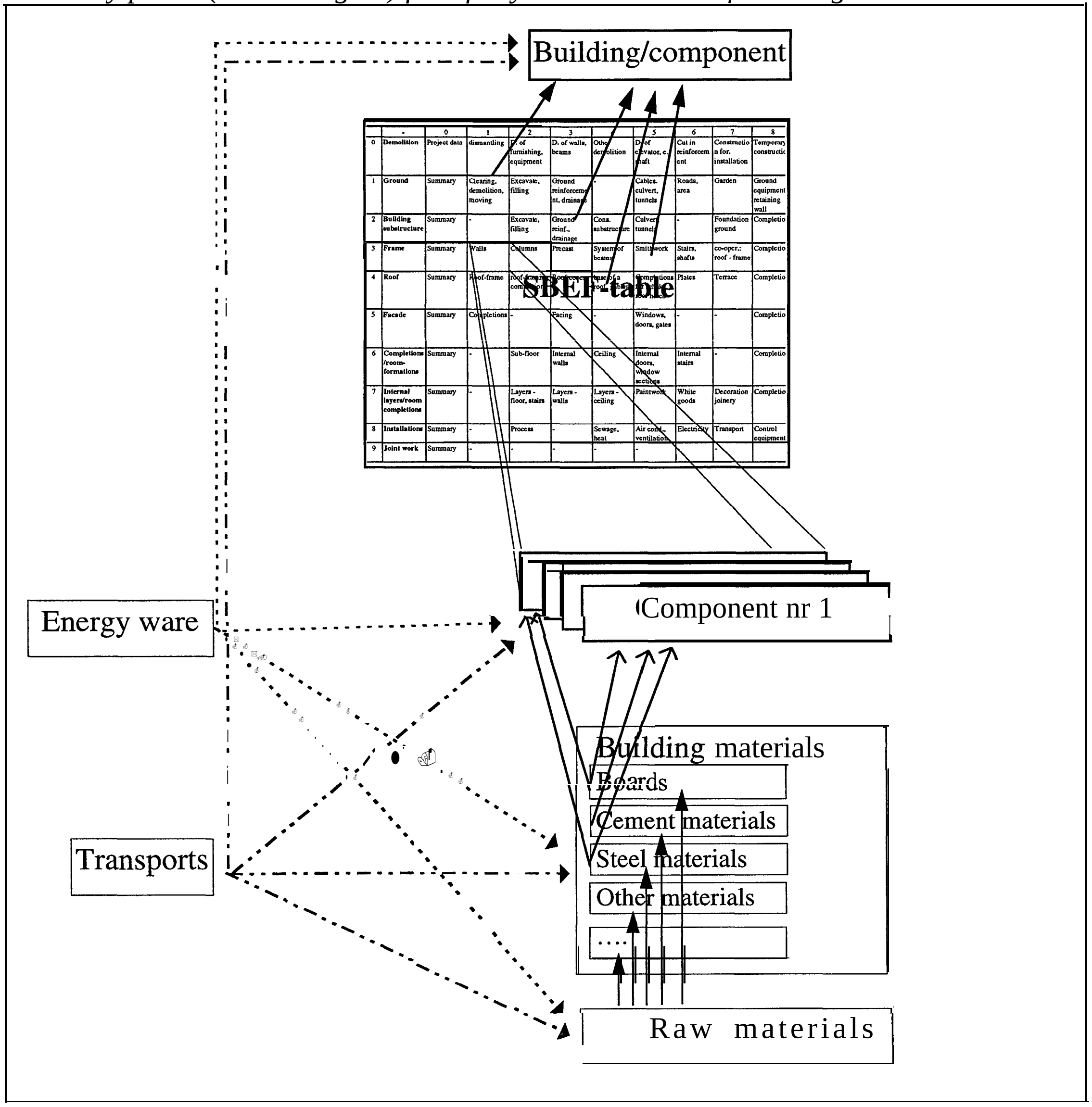
[2] The meaning of a *single unit* is that a data set is stored in the database once.

[3] LCA-data for a production process which has been subjected to allocation is not independent of the goal and scope of an LCA-study.

products[4]. Consequently, the data set may be reused in studies with similar goals and objectives. This will make the representation of data a strategic one, which over time, will generate more available LCA-data for the building industry at large.

The complete data structure that organizes the inventory data for the first inventory phase (cradle to gate) for life cycle analysis of buildings is presented in figure 3 . Here structural components for LCA-data of modes of transportation and energy wares have been introduced. These types of data sets were handled as general data that were available anywhere in the inventory when no other more specific (measured or site specific values of transport and energy related emissions to air water and ground) data were available.

Figure 3 The complete data structure that organizes the inventory data for the first inventory phase (cradle to gate) for life-cycle assessment of buildings.



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[4] This statement i related to a certain view of the use of materials and products. In this case, it is the usefulness of materials and products for the building industry, hence the LCA-data becomes independent of the goal of the study for studies performed within the building industry.

3.1.3 Comparison of the implantation of the data structure in two analysis tools

Easy update and consistent representation of data sets in the structure as well as possibility to expand the structure were important LCA-issues for the data structure for the studies. These features heavily depended on the analysis tool to support the feature to link the contents of a data set in to another data set, as in the SPINE-Ecolab software. This feature was not supported by the LCAiT-software. It made this tool less suitable for the needs that had to be fulfilled to get the proper use of the structure. However, if the only question stated in the case studies was to assess the environmental impact of the frames, the LCAiT tool would have been suitable for the task regarding straight forward inventory calculations.

4 Hot spot analysis and the use of the data structure and analysis tool

The data structure proved to be quite useful when drawing conclusions in the second case study [3], were three dwelling and warehouse frames respectively were analyzed. In the impact assessment of the production phase, three assessment methods were used (the EPS- (EPS), Environmental Theme- (ET), and Ecoscarcity-method (ECO)) to find where the hot spots of the production phase were located. This question was raised in the earlier study [2] but was not answerable within reasonable frame of time and money. Due to a favorable combination of computerized analysis tool and the data structure, this question was easily answered in the second case study. The hot spot results are present in table 1.

Table 1 Table over how three assessment methods have spotted environmentally significant production processes in the production phase for precast-, in situ concrete and wooden frames [3].

Frame	EPS	ET	ECO
Precast frame	Cement	Reinforcement steel	Cement, reinforcement steel
In situ concrete frame	Cement	Reinforcement steel, cement	Cement, reinforcement steel
Wooden frame	Oil, plaster-boards	Decibel 2, plasterboard	Plasterboard

This hot spot analysis were empowered by the data structure, linked data sets and the assessment engine provided in the Ecolab analysis tool. In turn, the SPINE structure granted the feature of linking the contents of the data sets. If, for each frame, the data would have been aggregated, this analysis would have been quite time consuming and difficult to perform, as in the first case study [2] were the analysis tool did not provide feature of linking data sets.

5 Discussion and conclusions

Generally, the data structure presented in this paper tries to cover the information presentation problem by organizing the inventory data for the production phase in a, to the building industry, customary fashion. It also tries to support the system boundary keeping issue of the inventory work by leaning on a computerized database technique permitting and supporting linking of data sets for the production processes. The view of the building as a material system is however limited. The data structure is designed for the environmental assessment of building materials in a functional context of the building material producing industry. To achieve this goal, the view of the building as a system had to be set to the one of the production phase were building materials are assembled to functional products. It might be put forward that what you get is, at the best, what you have designed and planed for, i.e. saying that the design phase is very important for the over all performance of a building. However, Swedish environmental studies [2], [3], [6] shows the service life phase to have the largest environmental impact of the three phases of the life-cycle of a building over 50 years; especially the environmental impact of the providing of heating energy used during the service life. The structure presented are mainly concerned with the data for the environmental impact of the materials used in the building in the production phase. In a larger context, this is perhaps of a more limited interest, with the assumption that the present technique of providing energy wares will be the same in the future. If assuming a change in this system (towards lower impact), the impact of material production will become a relatively higher compared to the providing of energy wares. Therefore, a development towards supply of heating energy with lower environmental impact will redirect the environmental attention towards the material production phase.

Acknowledgments

The development of the issues presented in this paper are based on the LCA-case studies of building frames which were financed by Scansem and the Nordic council of ministers.

References

[0] Ericson, B., Johansson, B-M., (1994) *Bostadsbyggande i idé och praktik - Om kunskaper och föreställningar inom byggsektorn* (in Swedish), Lund University Press, Lund, Sweden.

[1] Consoli F., (ed) et al, (1993) Guidelines for Life-Cycle Assesment: A "Code of Practice," SETAC Sesimbra.

[2] Bjorklund, T., Jönsson, A., Tillman, A-M., (1996) *LCA of Building Frame Structures - Environmental Impact over the Life Cycle of Concrete and Steel Frames,* Report 1996:8, Technical Environmental Planning, Chalmers University of Technology, Göteborg, Sweden.

[3] Bjorklund, T., Tillman, A-M., (1997) *LCA of Building Frame Structures - Environmental Impact over the Life Cycle of Wooden and Concrete Frames,* Report 1997:2, (in Swedish), Technical Environmental Planning, Chalmers University of Technology, Goteborg, Sweden.

[4] Björk, B-C., *(1993) Byggproduktmodeller: nuläget,* Statens råd för byggnadsforskning 1993:27 (in Swedish), Stockholm, Sweden.

[5] Werrnelin, I., (1983) *Aktiv kostnadskalkylering med hjälp av BSAB-systemet,* AB Svensk Byggtjänst (in Swedish), Stockholm, Sweden.

[6] Adalberth, *K.,* (1995) *Bygga, Bruka, Riva* (in Swedish), licentiate thesis, LTH, Lund, Sweden.

Energy Implications of the Transportation of Building Materials

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Abstract

The embodied energy is a significant factor in the whole life energy consumption of a building. Its proportion of the total energy consumption attributable to a building throughout its life is increasing as improvements in thermal performance and energy efficiency of systems reduce the energy consumption during the occupied phase of the building life.

The embodied energy can include all energy attributed to a building material from its original source through to construction on site. This paper considers the component of embodied energy that is attributable to the transportation of the materials. It is based on a case study undertaken of a single construction site, determining the energy consumed in transporting the construction materials to site. The results of this study are based on the energy consumed in delivery only, the fuel consumed for a one way delivery journey.

Literature search identified that common assumptions made by different researchers when evaluating transportation by road vary between 1.18 – 4.5 MJ/tonne/km. However these figures are assumed to include allowances for other aspects of the energy consumed that can be attributed to transportation such as return journeys and. the manufacture and maintenance of vehicles and roads.

The paper shows that for a particular study of a site in Brighton 1.5% of the total embodied energy was attributed to the energy consumed in the delivery of the materials.
Part load delivery and packing ratio are identified as factors affecting the energy consumed in transportation of materials and these issues are discussed with reference to the Brighton case study.
Keywords: Embodied Energy, Transportation

1.0 Introduction

The life cycle of a building commences with the winning of the raw materials that are usedto produce building materials and components and ends with the final disposal of those materials after demolition of the building and the re-use or recycling of suitable products. It includes all of the stages of construction, operation and demolition as depicted in fig. 1.

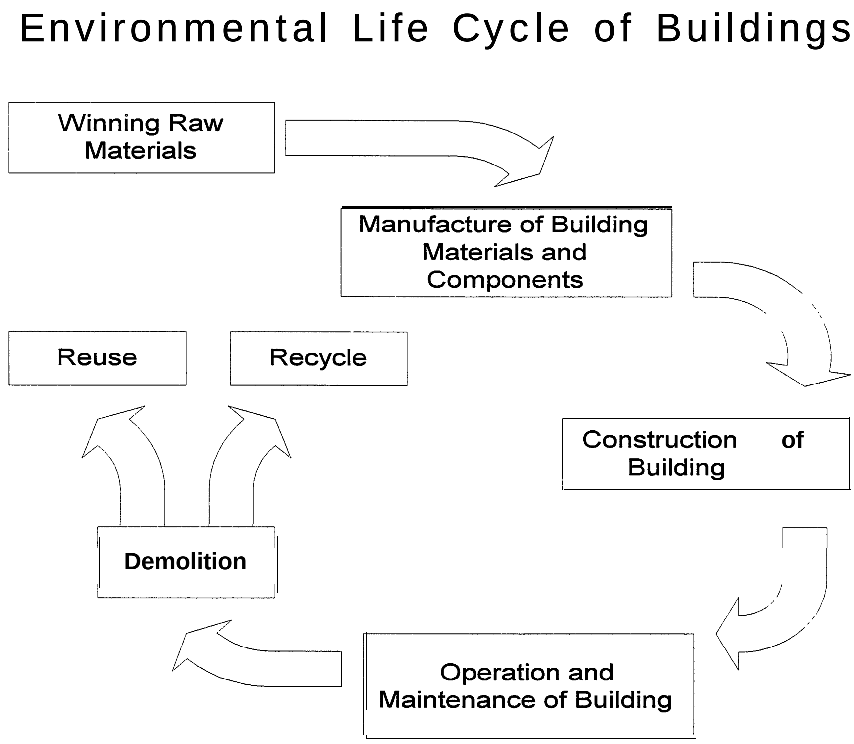


Fig. 1 Environmental Lifecycle of Buildings

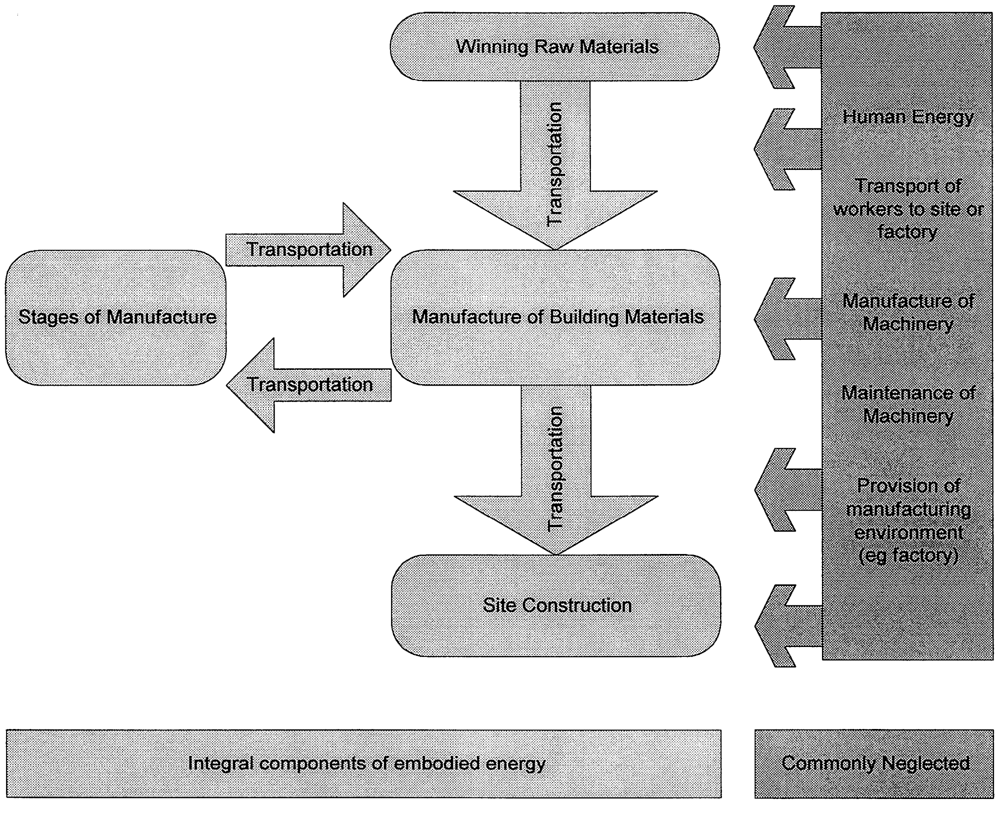
Throughout its life cycle a building will consume energy, generally in the form of fossil fuels. The consumption of fossil fuels results in the depletion of natural resources and in the production of pollution with its subsequent problems such as global warming and acid rain. It is estimated that more than 50% of UK energy consumption can be attributed to buildings and a similar proportion of the carbon dioxide emissions.

Much research has been aimed at understanding the energy consumption of occupied buildings and at reducing that consumption. However it is estimated that the delivered energy embodied in the constituent building materials and components is 350 PJ per annum (equivalent to 20% of the annual energy consumption in the UK domestic sector) and is responsible for 8% of the national carbon dioxide emissions. (1)

This paper is based on research undertaken at the University of Brighton aimed at improving our knowledge of the total embodied energy of building materials. In particular it studies the component of the embodied energy that is attributable to the transportation of those materials. The research project was sponsored by the Engineering and Physical Sciences Research Council.

2.0 Embodied Energy

The embodied energy of a building material or component is the total energy consumed in winning the raw materials, manufacturing the components and constructing the building on site. It includes the energy consumed for transportation within and between each of the stages leading to the completed building as shown in fig.2.



.Fig. 2 Components of Embodied Energy of a Building

2.1 Boundaries

A full audit of the embodied energy of any item can be very complex and there are diminishing returns with respect to the accuracy of the calculation the further removed the analysis becomes from the item under consideration. As a result the evaluation is often simplified and Fig.2 presents a commonly accepted definition of the embodied energy of a building.

Calculated in this way embodied energy figures are clearly site specific. They are related to the specific materials, suppliers and efficiency of distribution and delivery route. There is however generally no need for such a precise figure to be determined in order to provide useful data for building designers.

Published embodied energy figures for common building materials vary enormously and there is often little indication of what has been included in the analysis or how they have been obtained. Common exclusions are shown down the right hand side of Fig.2 but the transportation component is also often omitted or considered using gross simplifications.

3.0 Transportation Energy

This paper focuses on the energy consumed in transporting building materials from their origin to the building site and highlights a wide variation for different materials.

It is appreciated that the transportation component of embodied energy is often small compared to the total embodied energy of a material, but investigations have shown that in general, oversimplifications are made when estimating this component.

It is common practice to estimate transportation energy embodied in building materials through the use of a standard consumption in MJ/tonne/km.

Estimations of energy consumed in the transportation of building materials vary considerably and table 1, based on an original by Lawson (2), presents published figures for estimates used in Canada, Denmark, the UK and the USA. There is however no indication of the basis on which these figures were determined and comparisons are therefore dangerous.

Road Vehicles		
Country	MJ/tonne/km	Reference
Canada	1.18	(3)
Denmark	1.44	(4)
UK	4.50	(1)
USA	2.13	(5)

Table 1. Published figures for vehicle transportation energy

The research undertaken at Brighton has focussed on the delivery of materials to a single building site situated on the Brighton seafront and full details of the measurements have been published elsewhere (6). Vehicle fuel consumptions were calculated based the consumption of diesel with a calorific value of 35.7 MJ / 1 and vehicle efficiencies were based on the miles per gallon figures published in Philips (7).

A summary of the results of this study is given in table 2. The energy consumption figures are an order of magnitude lower than the estimates shown in table 1, however they represent only the energy consumed in the process of delivery and not the total amount of energy that can be attributed to the transportation of the materials.

Material	MJ/tonne/km	Material	MJ/tonne/km
RMC Concrete	0.10	Chipboard Flooring	0.29
RMC Mortars	0.05	Plasterboard	0.24
Dense Concrete Blocks	0.02	External Plaster	0.62
High Density Blocks	0.09	Internal Plaster	0.48
Thermal Blocks	0.05	Windows	0.33
Concrete lintels	0.72	Roof Slates	2.55
Structural Steel Beams	0.08	Celtex Insulation	7.92
Steel Shuttering	0.16	Angle Ties	49.24
Concrete Reinforcement	0.36	Zinc phosphate paint	1.34
Roofing timber	0.15		

Figures estimating the total energy consumed in transportation would include:

- fuel consumption in the delivery of materials
- fuel consumption in the return journey of the delivery vehicle
- attributable proportion of the energy consumed in the manufacture and maintenance of the vehicles

- attributable proportion of the energy consumed in the construction and maintenance of the roads

The components found to consume the most energy in transportation in the Brighton study were the steel beams, accounting for 18% of the total energy consumed in transportation. The steel shuttering and the ready mixed concrete were the other major proportions of the transportation energy, each representing approximately 11% of the total. It has been shown that these figures, based on consumption for delivery only, represent approximately 1.5% of the total embodied energy of the materials, when related to an average of published embodied energy figures.

4.0 Identification of Key Issues

Analysis of the results identifies that the delivered quantity of materials and the relationship to the maximum payload of the delivery vehicles are important factors in determining the energy consumed in transportation.

Vehicles may not be carrying their full payload capacity for a number of reasons and these are considered further under the headings of part load and packing ratio.

Part Load

A construction site may have received part load deliveries because:-

- The total site requirements are for less than a full load and the manufacturer or haulage company cannot schedule a full load.

An example of this can be seen in the delivery of angle ties of which only 0.1 tonnes were required on the site. These were delivered as a single load in a 4.5 tonne truck over a distance of 369 km.

There are of course a number of reasons why some deliveries need to be made in this way, but the relative energy cost is high. Careful planning of ordering schedules from the site and delivery schedules from the supplier would reduce this component.

- The restrictions on site storage are such that the total requirements for a material cannot be ordered at one time resulting in part load orders.

This problem was experienced in the delivery of thermal blocks where the 3 14 tonnes required were delivered in 22 separate deliveries. On this occasion it was not caused by part loading individual vehicles as smaller vehicles were used, but naturally the overall distance travelled was far greater than it needed to be.

- Security on the site is such that sub-contractors are unwilling to order the full requirements for fear of theft.

Loose materials are generally the responsibility of the sub-contractor until built into the building. Valuable materials that can easily be removed from site are therefore often delivered in small quantities.

On this site the plaster for the building was delivered in 14 separate journeys, once again increasing the distance travelled. However in this case the fmal leg of the deliveries, from supplier to site, were also at only 65% of the possible payload.

These issues will be affected by the material's distribution network, the management of the transportation system and the site management. The ability to organise full load distribution will be affected by whether the transportation is being undertaken by a manufacturers supplying their own products or by a specialist haulage contractors who might have the opportunity to plan a more efficient schedule for individual vehicles.

Packing Ratio

The nature of the building materials or components being transported dictate the type of vehicle being used which may result in the maximum load not being carried.

- The physical shape of the materials or components may make it impossible to load the vehicle to its maximum load.

The steel shuttering was a typical example of this effect as for each section of the journey the vehicles were only carrying approximately 25% of their payload capacity.

- The density of the material may be so low that it occupies a large volume.

The rigid insulation materials used on the site weighed a total of 1.1 tonnes but for the two legs of the journey travelled in a 25 tonne and 18 tonne vehicles.

These results do not identify inefficiencies in delivery but highlight limitations of the existing transportation system.

5.0 Conclusion

This project has resulted in the determination of transportation energy consumption figures for the full range of construction materials to a specific building site in Brighton. These figures are site specific and depend upon the specific set of circumstances relating to the building and its construction programme. The calculated transportation energy figures should therefore not be taken as transferable to any other construction site.

However the key factors raised by this study are widely applicable and their sensitivity need to be considered whenever embodied energy figures are evaluated.

The transportation energy calculated in this project, based on fuel consumption for delivery only, represents approximately 1.5% of the total embodied energy when published embodied energy figures are used. This figure will naturally increase when return journeys, vehicle manufacture and maintenance and the road network infrastructure are considered. Further, it relates to published embodied energy figures, which themselves vary by more than 100% in some instances. Nevertheless it serves as an indicator as to the significance of the transportation component for individual materials.

The key factors of part load and packing ratio have been analysed identifying common occurrences that make it impossible to optimise the efficiency of delivery. The more obvious factors of vehicle used, distance travelled and route taken, have also been considered and extenuating circumstances identified.

References

1. West, J., Atkinson, C. and Howard, N. Embodied Energy and Carbon Dioxide Emissions for Building Materials. First International Conference on Buildings and the Environment, CIB TG8, BRE Watford,UK (1994)

2. Lawson, W. Embodied Energy of Building Materials, Environmental Design Guide, Royal Australian Institute of Architects. (1995)

3. Trusty W.B. Unit Factor Estimates, Model Development and Related Studies, Phase 2 Summary Report, Forintek Canada Corporation. (1993)

4. Krogh H. Personal Communication. Danish Building Institute (1994)

5. Malin N, On using Local Materials, Environmental Building News, Volume 5 No. 5, (1996)

6. Miller A. J. Transportation Energy Embodied in Construction Materials, 2nd International Conference on Buildings and the Environment, Vol 1 pp477-484, CIB TG 8, Paris. (1997)

7. Philips, Transport Cost Tables, Motor Transport, Nov. 16 (1995)

Ecological water reservoir

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Abstract
Due to the noxious consequences of asbestos fibres incorporated to the human body, and because this material is used in different industries including construction industry and specially drinking water supply as well as domiciliary reservoirs, a subsitute material has to be found for the construction of the tanks.

Bibliographical analysis is the used methodology to stablish asbestos risks on health, and experimentation for material study.

The best results are obtained on those mixtures with bagasse aggregated, but new mixtures will be studied.

It is known that Xvegetal fibres are used energetical consuption will be lower. On the other hand incorporating vegetal fibres which can be found in the region costs could decrease in relation to the ones traditionally used.
Keywords: water reservoir, cement asbestos, vegetal fibres.

1 Introduction

Many samples of fibre use exist in nature to reinforce weak and fragil matrix. Low density wood through a cellular polymer compacted to chips provide a composed material naturally reinforced.

The use of straw in construction of sun-dried bricks (adobe) and mug walls, horse's hair or sisal incorporated to gypsum have been known and used for many centuries.

Asbestos was probably the first inorganical fibre used as a reinforce in compound materials. It is known that it was used in Finland since 2500 b.c. to reinforce potter's art pieces. It is still used currently in the construction of different elements of daily use, such as domiciliary water reservoirs even when it noxiousness to human help has been confirmed.

At the Stability Department of Engineering College - UNNE - (Northest National University) several technological investigation have been performed over mortar and concrete with natural aggregates such as sawdust, rice skin, as well as sugar cane bagasse 1) and esparto grass.

In October, 1996 the first Meeting of Projects of Cience and Technology Precompetitivity for Development was performed at the Central Library of the Autonomous University of Queretaro, Mexico. During the Meeting an specialist of the Scientific Research Centre of Yucatan, Pedro Herrera Franco exposed that the natural fibres use in concrete working up for construction will decrease industry costs and that fibres that are unprofitable today like sugar cane bagasse could contribute material within international patterns.

Noxious and sometimes ominous consequences produced by asbestos fibres incorporated to the human being trough aspiration or ingestion are well known.

Asbestos use is very diffused in construction industry, acoustic products, brakes, clutches, insulating materials, ceiling and covering, etc. On the other hand most people inclose it daily, because water supply is made through water pipe lines constructed with cement-asbestos as well as domiciliary reservoirs (elevated tanks, and reservoirs). It is importand to find valid alternatives which can perform the same function, in order to diminish the risk for human health.

Asbestos fibres can be replaced for vegetal fibres duly treated.

2 Objetives

- Establish the relationship between asbestos incorporation in human beings and the risks for their health.
- Determine a mortar mixture and vegetal fibres for the construction of reservoirs that can replace the cement asbestos currently used.

3 Methodology

Analitic, experimental, and deductive methods will be used.

3.1 Bibliographical analysis

Study of preliminary bibliography.

Research and selection of the specific bibilography to carry on the project.

3.2 Laboratory essay

3.2.1 Dosage tests to determine the most competent compound for the stablished purpose. .

For this essay IRAM 1622 Norm was followed "Determination methods of compression and flexure resistances".

3.2.2 Physical mechanical tests: Compression, tensil stress and flexure over test tubes performed with different mixture.2)

3.3 Laboratory work

Analysis and procedure of the results, in order to determine the material properties.3)

4 Working material

4.1 Construction material for test tubes

- Cement
- Sand
- Fibres: bagasse (husk from Sacharus officinarum), esparto grass (Spartina argentinensis)
- Water
- Additives (if necessary)

4.2 Equipment

Machines and instrumental needed for confection and test of the test tubes

4.2.1 Tubes

- 4 cm x 4cm x 16cm test tubes were molded with 12 % of esparto grass in cement weight.
- And prismatic test tubes with a lenght of 80 cm and a transversal section of 10cm x 10cm with 10 % of bagasse in cement weight.4)

4.2.2 For small test tubes flexure essay a CIENTEC machine of 3000 kg was used. The big test tubes were tested to flexion with a SUZPECAR of 100 tn.

In compression essay of both types of test tubes and universal press AVERY of 100 tn was used.

5. Results

5.1 Asbestos, an environmental contaminant

Asbestos can be found in nature, incorporated to rocks as fibres, with same other extraneous elements. So after it is extracted it has to be purifyed. The operation consists in making a crushed without breaking the fibres, afterwards it is removed and then separated putting through it an air flowing that carry away the fibres and left heavy elements as remnant.5)

Asbestos is formed by several fibrous mineral composed by hydrated silicate. The most abundant elements are chrysolite, chrosydolite, auronite, for which reason are the most dangerous. It is from a chemical point of view and hydrated magnesic silicate that may contain iron, whether as iron oxid or calcium oxid combined.

In the word about 6 (six) million tons of these mineral are extracted from mines in a year.

A great number of people are exposed to the perjudicial consequences of inhalation or ingestion of asbestos fibres. Their incorporation to the human body can cause not only a diffuse interstitial fibrosis but most important a higher frequency in different kinds of cancer, mainly a broncogenic carcinoma and mesotelioma.

Just in the construction industry, and in shipyards 3 to 5 million workers are exposed.

It was shown that a 38 % of isolater installers group presented asbestosis, even when these workers were exposed to concentrations about 5 millons of asbestos particles in one feet cubic of air, which is considered as the limit value for those expositions.

On the other hand, it is perfectly confirmed the indirect exposition, as it is shown by mesoteliornas frequency in workers family. A population is also exposed to contamination by inhalation or ingestion, what was shown by the presence of asbestos fibres in lungs of about 20 to 50 % of big cities residents in later autopsy.

The appareance of the disease after the exposure is variable. It could be brief, one or two years, but generally the symptoms take much more about 10 or 20 years to come up.

Aproximately over 15 % of the patients with a severe asbestosis develop broncogenic cancer 20 or 40 years later (later cancer). The danger for developing this type of cancer increases 10 times in people with asbestosis and 90 times in smokers. In different investigations carried on in patients with asbestosis, 1 from 5 deaths was caused for lung cancer , and 7 % correspond to peritoneum and pleura mesotelioma. There is also a double proportion with respect to the normal of esophagus, stomach and colon carcinoma.6)

5.2 Alternative material searching

Flexure and compression essay results over 28 days, of both mixtures (esparto grass and bagasse) are shown in the following tables:

Test Tubes	Flexure Resistance		Compression Resistance	
N⁰	Rupture Load [Kg]	σ Rupture [Kg/cm²]	Rupture Load [Kg]	σ Rupture [Kg/cm²]
1	13,59	3,18	39 52	2,44 3,25
2	13,59	3,18	65 52	4,062 3,25
3	13,59	3,18	65 65	4,062 4,062
4	9,68	2,27	65 78	4,062 4,875
5	13,59	3,18	65 65	4,062 4,062
6	13,59	3,18	78 52	4,875 3,25

Table 1: Reinforced test tubes with esparto grass

Test Tubes	Flexure Resistance		Compression Resistance	
N⁰	Rupture Load [Kg]	σ Rupture [Kg/cm²]	Rupture Load [Kg]	σ Rupture [Kg/cm²]
1	182	20,47	1560	15,60
2	150	16,87	1925 1980	19,25 19,80
3	195	21,94	1911	19,11
4	160	18,00	2400 2520	24,00 25,20

Table 2: Reinforced test tubes with bagasse

6 Conclusions

• How asbestos fibres produce the lung fibrous reaction or the way that provokes a carcinogen action in different organs is still unknown. But even when the pathogenesis is not known, the existing data show that asbestos strength the action of other carcinogen hydrocarbons.

Large cities population are exposed- to this contaminant and particularly asbestos workers and users.

• The obtained resistances in mixture with esparto grass have been little encouraging, even more in the compression ones, new dosifications will be tested with another fibres percentages.

Mixture results with bagasse aggregate are more optimistic, what allows to continue with them to find searching alternative material.

7 References

1) Hess, A. and M. Buttice. (1990). Compound materials from vegetal fibres as agglomerated irregular micro-enfiorcemente and Portland cement used in pieces for low-cost housing. ***2nd. International Symposium on vegetable plants and their fibres as building materials.*** Ed. RILEM. Brasil.

2) Canova, M.F.; Selva, N.H. and Kawiche, G.M. (1992). New economical solutions for improvement of durability of Portland cement mortars reinforced with sisal fibres. ***Materials and Structures.*** Ed. RILEM, Park. V 25. pp. 417-422.

3) Béton de fibres. Synthése des etudes et recherches réalisées au CEBTP (1994). ***Béton.*** Park V 305, pp. 88-119.

4) Sarja A. (1989). Structural wood - fiber concrete. Versatile special concrete utilizes local, natural materials ***in*** flexible manufacturing process. ***Concrete International.*** pp. 45 -49.

5) UNBA - CEA (1963). ***Introducccidn a la Construcción.*** Ed. UNBA - CEA. Buenos Aires.pp. 120 - 125.

6) Robins, S.L. ***y*** Cotran, R.S. (1984) ***Patologia Estructural y Funcional.*** 2da Edición Interarnericana. Madrid. pp. 484 - 520.

The use of earth in the construction of ecological dwellings.

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Abstract
The use of earth as a construction material presents an evolution from remote times. It was used in the construction of fortifications, temples and dwellings. Today, due to the lack and costs of energetical products, techniques should be improved in order to utilize material that can reduce these costs. The use of earth for its low consumption of energy -which is obtained with a good architectural design, thermical control, recycle posibilities of the material, the limited incidence of transportation, and the absence of combustion in its elaboration- constitutes a powerful ally in the defense of ecology. Earth presents several economic advantages: it occupies almost exclusively local resources, workmanship, raw material, and it requires just a little investment for industrial equipment. Although the use of earth has been a widely known technique for many years, it is not currently used in this area. Superficial natural earth representative of our region is a clayey soil and it is not apt for this kind of construction. The incorporation of sand with a fineness modulus greater than 2.50 and with predominance of thick fragments permits to obtain an artificial soil apt for the fabrication of modular elements of soil cement. Based on flexure and compression results of normalized test tubes, quantities of soil-cement with the best behaviour were chosen for blocks elaboration. Artificial soil B (60 % land + 40 % thick sand) mixed with 10-12 per cent of cement permits to obtain the best results in resistance, retraction, and durability. It arises then that using an actualized technique and adequate projects it is possible to construct low costs dwellings with both good thermic and acoustics conditions and durability.
Keywords: construction material, earth, ecological dwellings, modular elements of soil-cement.

1 Introduction

Since cities were invented, 10 thousand years ago, men has used earth to construct fortifications, temples and dwellings. The use of earth mixed with cement supported by scientific bases started with the construction of a 2,4 km road section in Johnsonville - South Caroline - U.S.A, with successful results. The French architect Francois Cointreaux (1740-l 830) invented in 1787 different processes to "stabilize" earth and make it more resistant in its mechanical and chemical aspects (1). He also published several studies that were widely aknowledged in Europe, America and Australia. His charts helped the constructing of public buildings, castles and dwellings up to 5 floors.

In the beginning of the XX century this kind of architecture starts to languish before the appearance of industrial materials such as steel, cement and reinforced concrete. Since 1972 the energy and the economic crisis lead to changes in the way of thinking and started to appear alternative methods specially those concerned with energy saving in construction (1). There are recent experiences of constructions performed in developed countries like France and closer to up Chile, Brazil and Paraguay (2).The construction of such dwelling in our country was posibility of two engineers, Adolfo Grissi and Victor Carri who worked at the Essay Laboratory. At the same time the Argentinian Institute of Portland Cement built - with the same material- a dwelling that was exposed at the Cattle Exposition of the Rural Society in 1944 (3). There were several experiencies with the overlapping of soil-cement in many Argentinian provinces: Chaco 1960, Tucuman 1967, Jujuy 1969, and in different localities of Buenos Aires: Lobos 1971, and Junín 1973, as well as Mendoza 1977, Salta 1981, Chaco 1991, with excellent results (3). Although earth construction is a well known technique over the years, it is not currently used in our region except in indigenous and low economic resources population (2). Overlaping earth-cement provide the rationality of its fabrication process and technical qualities, such as: high mechanical resistance, moisture resistance, dimensional regularity and a competitive cost (4). Overlaping earth-cement uses as raw material non fertile land: ecological brick (5). Earth that comes from the fertile layer is not apt for the reaction with the cement and the hardening, on the contrary, they are more advisable the ones that have in its composition a high percentage of sand. This land hasn't to be calcine because with the cement incorporation, the particles behaviour is modified, the stability improved, giving it more resistance and durability (6). The superficial and natural earth representative of our region is a clayey soil and it is not apt for this kind of construction. The incorporation of sand with a modulus greater than 2.50 with predominance of thick fragments permits to obtain an artifical soil apt for the fabrication of modular elements of soil-cement.

According to the flexure and compression results the best quantities for elaborating the blocks were chosen (7). Artificial soil with 60 % of soil plus 40 % of "thick" sand mixed with 10-12 per cent of cement allows to obtain better results in mechanical resistance, hardening and durability. It arises then, that using an actualized technique and adequate projects it is possible to construct low cost dwellings with both thermic and acoustics conditions and durability.

1.1 General objetives

Utilization of a natural and no contaminant materials. It practically uses any kind of soil, except the organic, no renewable. It is an ecologic system of construction.

The exploitation of regional materials, with a minumun cost, what allows to reduce the construction cost. The use of earth avoids the importation of expensive materials or the comsuption of energy to produce them. The transportation of materials is reduced only to the cement movement because the overlapping is produced at the place of work.

The use of unskilled workmanship. The utilization of this material does not require skilled workmanship, needs only a mason and the rest of the staff can be just assistants.

1.2 Particulars objetives

Elaboration of modular components of soil- cement for low cost dwelling, from an existant and regional clayey soil. Due to the technic and economic advantages of this material, the existing deficit of dwellings can be reduced.

2 Material and Methods

2.1 Soil-Cement: identification and characteristics

Technically, any kind of soil with no organical substances can be "stabilize" with cement (6). A soil-cement is a compacted mixture of natural soil and cement with an optimal degree of moisture. The percentage of binding makes that the modular elements can perform the durability essay for "freezing-thawing" and "humidification drying" (8). It has an excellent thermical inertia and acoustics isolation (9). Its behaviour depends on the physical and chemical characteristics of its components and specially on the fine fraction (7). Researchers and institutions that made different studies on this particular topic established limits within which they considered that the most apt soil was: sand (40-80%), and clay - mud (60-20 %). A clayey soil was used in this study, which is representative of the superficial earth of this region. Its composition was as follows: according to the Unifyed System of Soil classification: it is a CH soil, inorganic clays with high plasticity, through the sifted of the thick fraction (particles > # N° 200), and from the Sedimentary essay of the fine fraction (particles < # N° 200), the percentages of our natural soil of sand, mud and clay were obtained: sand: 9.4% and clay+mud: 90.6%. Its unfavorable physical and chemical properties obligated us to realize a "granular stabilization" using sand in order to obtain an artificial soil apt for the study. Afterwards, cement percentages were analyzed to obtain the material for the manufacturing of the modular components. At the Soil Laboratory - Stability Department, Engineering College- samples of soil were investigated and granulometric curves, physical properties and composition obtained.

2.2 Natural soil

2.2.1 Laboratory essay
Laboratory conditions:
Temperature: 27 ° C
Relative moisture: 60 %

- Specific gravity: G= 2.64 - TEX norm N° **108 -** E
- Shieve washing N° **200:** 90.6% (passing particles) - ASTM D norm N° **1140 -**
- Liquid limit: **LL=** 63% - ASTM D norm N° 423 -

- Plastic limit: LP= 20.4% - ASTM D norm N° 424 -
- Plasticity index: IP= 42.6% - ASTM D norm N° 424 -
- Contraction limit: LC=10. 1% - ASTM D norm N° 427 -
- Natural moisture: 2.4% - ASTM D norm N° 2216 -
- Soil clasification (according to Unifyed System of Soil Clasification): LL= 63%
- Plasticity chart ⇒CH (inorganical clays with high plasticity). IP= 42.6%

2.2.2 Field essay (passing fraction # N° 40)

- Dilatation (agitation reaction): null
- Resistance in a dried stage (breakage characteristics): high to higher
- Toughness (consistency closer to the plastic limit): mean to high

Through the sifted thick fraction (particles > # N° 200) and the sedimentary essay of the fine fraction (particles < # N° 200) a granulometric curve was obtained and the contents of sand, mud and clay were measured in the natural soil. To determine the limits between these fractions by taking into account their size the M.I.T.(Massachusets Institute of Technology) Soil Classification System was adopted. Table 1.

Table l: M.I.T. Soil Clasification System

SAND		
THICK 2.0-0.6	MEAN 0.6-0.2	FINE 0.2-0.074
MUD		
THICK 0.074-0.02	MEAN 0.02-0.006	FINE 0.006-0.002
CLAY		
THICK 0.002-0.0006	MEAN 0.0006-0.0002	FINE 0.0002-Colloids

- Sand: 9.4%
- Mud: 68.1%
- Clay: 22.5%

These results allow to detect an insufficiency in sand contents and a high plasticity clays excess compared to the normal values previously mentioned. The real granulometric curve is the one in relation to the natural soil (N), and the pattern granulometric curve is in relation to the soil with the best percentage of sand, clay and mud (P). Figure 1. From this granulometric analysis we can determine that in order to approach the real curve to the pattern curve it is necessary to incorporate a determined quantity of thick fraction and a medium of a siliceaus sand -artificial soil-.

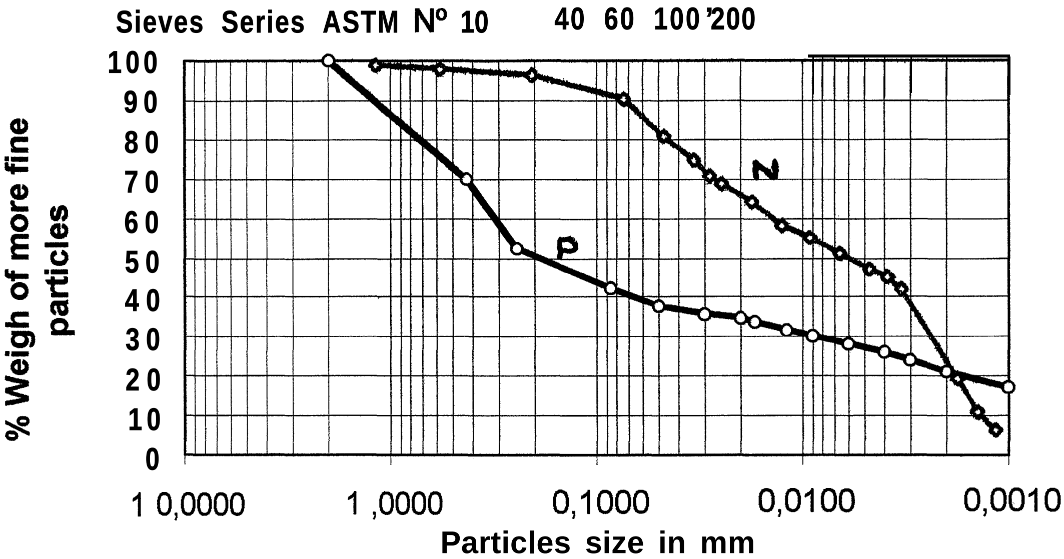

Figure 1: Granulometric soil curves for soil **-P-** and the soil material **-N-**

2.3 Artificial soils (A,B,C)

Granulometric analysis was undertaken on stabilized soil samples containing sand in three different quantities:

Soil A: 70 % Natural soil + 30 % "Thick" sand.
Soil B: 60 % Natural soil + 40 % "Thick" sand.
Soil C: 60 % Natural soil + 40 % " Mean" sand.
According to M.I.T. clasiffication and adjusting series of Standard of the American Society for Testing and Materials - A.S.T.M. -

The approximation of artificial soils (A, B, C) to the pattern soil -Figure 1- were verifyed. Different percentages of cement **(8- 1 O-12-14-1 6)** and tubes to analyze these soil-cement quantities behaviour were prepared according to I.R.A.M. norm Nº 1622.

2.4 Soil-cement blocks

2.4.1 Design

Blocks were obtained using a blockader, an improved version of the well known manual press CINVA-RAM and BREPACK PRESS, (10) built at the Stability department. It basically is a-rectangular box where the soil is deposited and pressed into blocks, three at a time. Blocks dimensions are: width: **12** cm, high: **12** cm, and length: 24 cm. There are trunkpyramidal elements at the bottom of the box and they are used to hollow the bricks when they are pressed. Figure 2.

2.4.2 Manufacturing

To mix the soil with the cement, both have to be dried in order to integrate them correctly (8). The high clay content of the natural soil produces dried and high toughness clods.

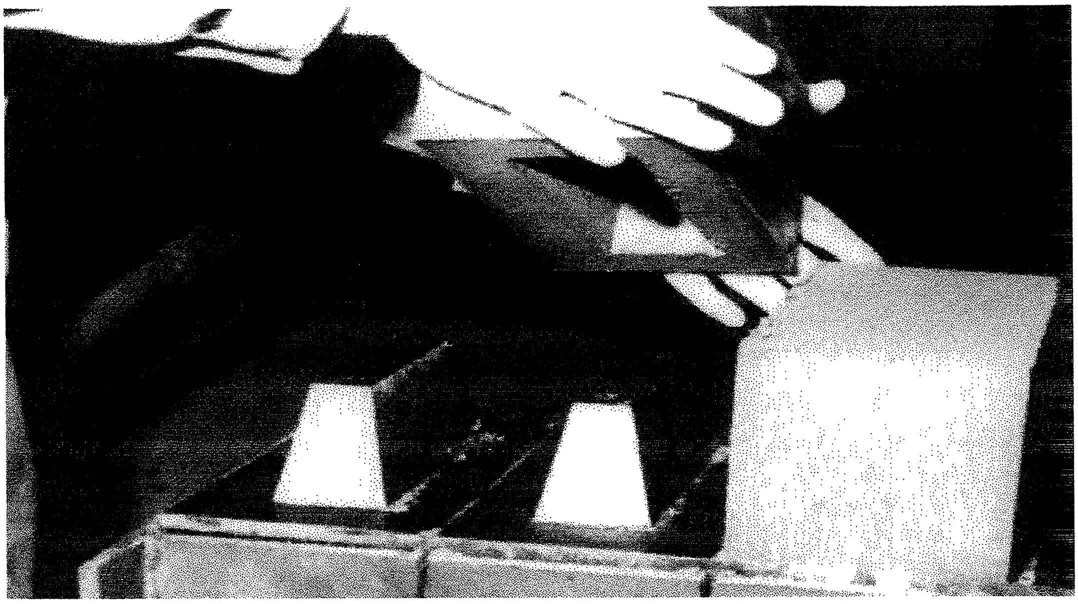

Figure 2: Blocks extraction from the blockader.

A cylindric and manual roller which has a diamenter of 35 cm, a length of 65 cm, and a weigh of 250 kg was used to facilitate the pulverization tasks of these clods and to increase the production of the available soil. According to the spectre of soil quality available the moisture content oscillates fi-om 8 % to 16 %. A water excess makes the compactation harder because of the slipping of the particles, and produces a greater tendency to fissure. There are two ways of verifying in situ if the mixture has the best moisture: 1) it must be compressed using the hands, and it has to adopt their shape without stain them, and 2) the pressed material must be dropped down from the shoulders height, and it has to disperse staying as it was before of being pressed (8). After the moisture verification the mixture was discharged into the blockader -Figure 2- for its compactation. Subsequently, the blocks were removed for their hardening. -Figure 2-. The hardening consists on spray the blocks over 7 days -at least once a day- and store them protected from the sun action in a ventilated place.

2.4.3 Essays

From the flexure and compression results of the normalized tubes, the best quantities of soil-cement were chosen for the blocks elaboration, which were the A and B soils with 8-10-12-14-16 per cent of cement.

On the other hand, in order to diminish the production costs -workmanship, materials and time- a new artificial and stabilized soil with natural sand from Paraná river was introduced. This sand has a fine modulus of 1,95 and it is representative of the siliceous sands that are comercially obtained. These blocks went through a simple compression essay using an universal press.-Figure 4-. The normalized pillars of blocks settled in mortar with the same quantities also went through a compression essay. Pillars were constructed to analyze the retraction effects, as well as the adhesion and durability.

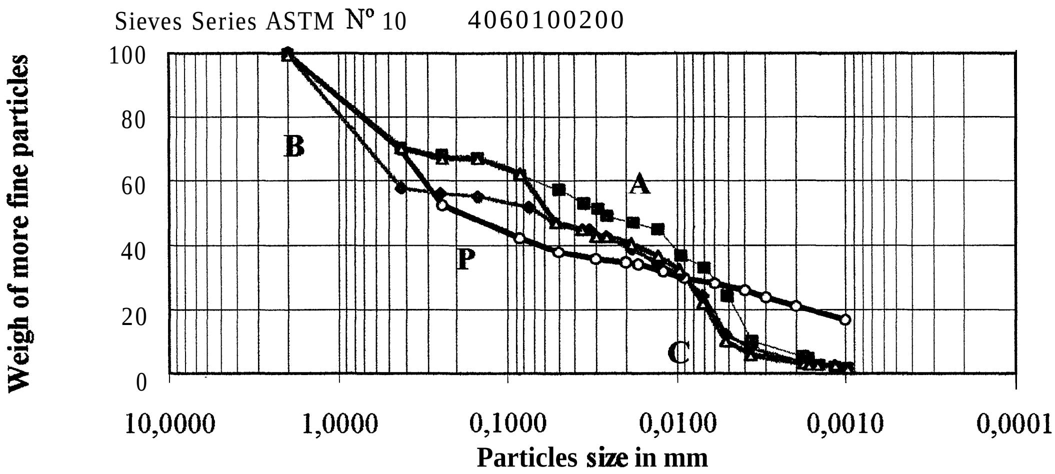

Figure3: Comparation between pattern soil curves (P) and artificial soils (A, B, C).

3 Results

3.1 Granulometric essay of the artificial soils.

<u>Soil A:</u> 30 % natural soil + 30 % '"thick" sand
Sand: 38,2 % LL: 45,8 %
Mud: 55,9 % LP: 16,5 % → according to S.U.C.S.: **"CL";** H.R.B.: A-7-6 **(15)**
Clay: 5,9 % IP: 29,3 %

<u>Soil B:</u> 60 % natural soil + 40 % '"thick" sand
Sand: 48,1 % LL: 44,9 %
Mud: 48,0 % LP: 18,1 % → according to S.U.C.S.: **"CL";** H.R.B.: A-7-6 **(10)**
Clay: 3,9 % IP: **26,8 %**

<u>Soil C:</u> 60 % natural soil + 40 % "mean" sand
Sand: 38,0 % LL: 25,3 %
Mud: 58,6 % LP: 12,3 % → according to S.U.C.S.: **"CL";** H.R.B.: A-6 (5)
Clay: 3,4 % IP: 13,0 %

3.2 Compression essay of the soil cement blocks

From the preliminary analysis of the tubes, artificial soils A and B were the ones with the best behaviour. The artificial soil D made of 60 % of natural soil and 40 % of natural sand without sifting was also included.

Maximum resistance values in compression at 14 days correspond to the mixtures with B soil, about 25 kg/cm. From the durability, retraction and mortar adhesion analysis the best results were obtained with B soil + 10-12 per cent of cement.

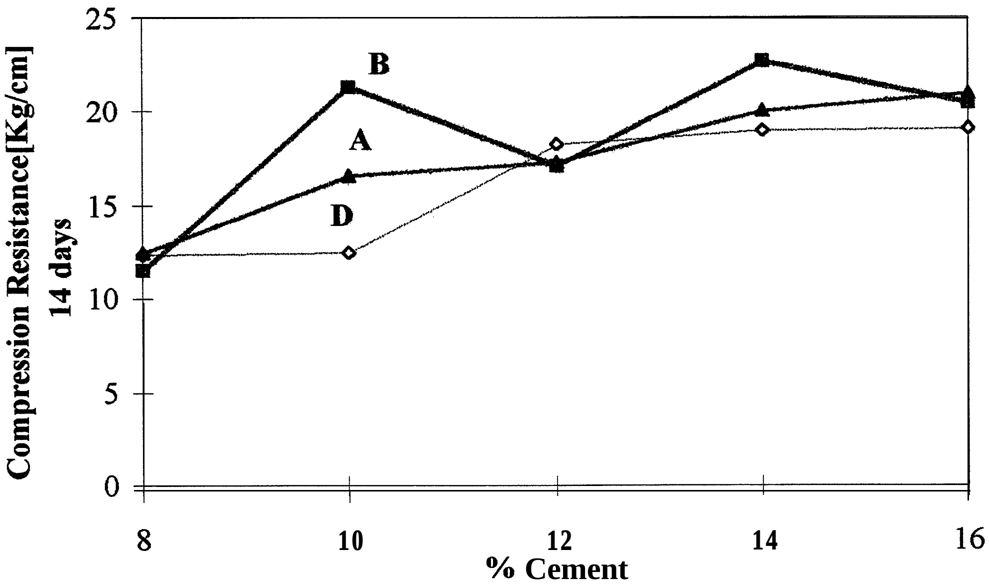

Figure 4: Compression resistant of soil cement for different percentages and artificial soils.

4 Conclusions

- An excess of clay produces important retractions, that leads to fissures and reduces the final resistances.
- Better mechanic properties were obtained when the relation between mud and clay was closer to the unit.
- The block retraction was controlled incorporating sand to the "stabilized"clayey soil, which also increased its resistance and durability.
- Production of this material occupies almost exclusively local resources - workmanship and raw material- which reduces the costs.
- The artificial soil B (60 % of soil + 40 % "thick" sand) mixed with 10-12 per cent of cement permits to obtain the best results in resistance, retraction and durability.
- The obtainment of thick sand through sifted increased the production costs, therefore, it is advisable to use a natural thick sand from the Paraná river, with a fineness modulus of 2,50.

5 References

1. Martinez de Aza, M. (1994) Las construcciones de tierra cruda hoy, *Revista vivienda,* Buenos Aires, Argentina.

2. Centro de Tecnologia Apropiada, CTA (1987) *Construir con burro- Parte A- El barro como material de construcción.* Facultad de Ciencias y Tecnologia. Universidad Catolica "Nuestra Señora de la Asunción", Asunción, Paraguay.
3. Mineo, N **(1993)** Autoconstruccion con suelo-cemento. Nuevas tecnicas. *Revista Casa Nueva,* Buenos Aires, Argentina.
4. CTA (1992) *Uso de la tierra y materiales alternativos en la construcción.*
5. CTA (1985) *Producción y Ensayos de Bloques de suelo prensados*
6. Etchichurry, D.(1993) El suelo como material de construcción, Instituto del Cemento Portland Argentino, *Revista Casa Nueva,* Buenos Aires, Argentina.
7. Romeral, J. et al (1986) Primeros resultados del trabajo de Investigación sobre la tierra como material de construcción, *Instituto Eduardo Torroja.*
8. Monicault, I. (199 1) Tecnologia del suelo-cemento, Dirección de Investigación Tecnologica Aplicada, *Instituto Provincial de Desarrollo Urbano y Vivienda, Chaco, Argentina.*
9. Merril, A. (1949) *Casas de tierra apisonada y suelo-cemento,* Windsor, Buenos Aires, Argentina.
10. CTA (1985) *Bloquera del CTA*

Ultrasonic bridge inspection using 3D-SAFT

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Abstract

Advances in the experimental equipment and data analysis have shown, that ultrasonic pulse echo technique can be used in bridge inspection to detect different types of defects

- injection faults in tendon ducts, because they lead to a loss of basic protection of the tendon steel and may result in corrosion damage
- compaction faults or honeycombing, because the reduce the concrete strength and therefore may influence the static stability.

To overcome the problems of low signal-to-noise ration and bad coupling conditions of the ultrasound to the rough concrete surface a combination of piezoceramic transducer and receiving laser vibrometer was used to scan a 2D aperture. The ultrasonic RF echoes received were digitized and stored in a PC for 3D-SAFT (Synthetic Aperture Focusing Technique) reconstruction, which performs a focusing of the ultrasound into the material leading to an improved signal-to-noise ration and a 3D-image of the internal structure of the concrete.

The EFIT-code (Elastodynamic Finite Integration Technique) was used to model the ultrasonic wave propagation in the concrete and the interaction with tendon ducts of good quality and the case of injection faults. These simulations showed, that the behaviour of the interaction differs for both situations leading to an evaluation scheme to detect injection faults. Compaction defects are detected by an increased attenuation of the ultrasound leading to a suppression of the echoes of e. g. the tendon duct.

In cooperation with the Federal Highway Research Institute (BASt) test measurements on a specimen containing artificial defects were carried out, which confirmed the prediction of the EFIT modelling.
Keywords: injection faults, modelling ultrasonic wave propagation (EFIT), prestressed concrete, reconstruction calculation (3D-SAFT), scanning laser vibrometer, tendon ducts, ultrasonic testing

1 Introduction

The structural integrity of post-tensioned concrete structures is primarily determined by the condition of internal ducts and tendons. Grouting faults in tendon ducts must be revealed as the tendons are susceptible to corrosion when they are not completely covered by mortar. Compaction faults around the tendon ducts are frequently other causes of damage and failure.

Today the regular inspections of engineering structures are mainly visual assessments. This implies that any damage is in general only identified when deterioration becomes visible. There is a demand for non-destructive testing methods in this area in order to establish the condition of structures and to identify faults before they become visible through deterioration effects. It will help to reduce costs and to extend the service lifespan, when regions to be maintained can be pinpointed early.

Non-destructive test methods such as radiography and impact-echo methods have so far been applied for identifying such problems. Radiographic techniques may only be applied when the component to be examined is accessible from two sides and moreover, these methods have their own attendant problems in connection with radiation protection measures. The second method has been widely applied, but its performance is judged differently.

We report on experiments using an ultrasonic echo system. To overcome the known difficulties encountered with ultrasonic testing of concrete due to the inherent properties of the material, an enormous progress can be stated in the last years [1][2][3][4]. For the method described in the present paper, ultrasonic signals in a so-called synthetic aperture are processed to obtain three-dimensional images and the ultrasonic backscatter and reflections from the area below the synthetic aperture are calculated. We used a bistatic measurement principle, i.e. separate ultrasonic transmitters and receivers were employed. The results were visualized and may be superimposed with the construction plan or the results of other imaging measurements.

In order to predict, what is possible to measure in concrete structures by use of ultrasonic echo methods, simulation calculations by the Elastodynamic Finite Integration Technique (EFIT) have been applied. The propagation of elastic waves in concrete was simulated in dependence of the concrete admixture and the presence of defects.

2 Experimental Set-up

Significant amounts of data of several thousand positions are required to reconstruct meaningful images. BAM has developed a special test arrangement with a laser vibrometer as the ultrasonic receiver in order to automate data recording and to reduce the problems of positioning and coupling the transducer [5]. The ultrasonic transmitter is piezoelectric with a centre frequency of about 100 kHz.

The laser vibrometer registers all surface vibrations within a wide frequency range of 0.1 mHz to 1 MHz, i.e. the vibrometer measures all relative motions between the vibrometer and the surface to be measured (in the direction of the laserbeam). Undesired vibrations may easily suppressed by frequency filtering and time averaging techniques [6].

If a large structure is to be examined, several surfaces areas with different transmitter positions must be scanned. The scanned areas should overlap to produce optimum results. The position of the tendon duct should be known to install the transmitter most effectively, this can be ascertained by the radar method [4][7][8].

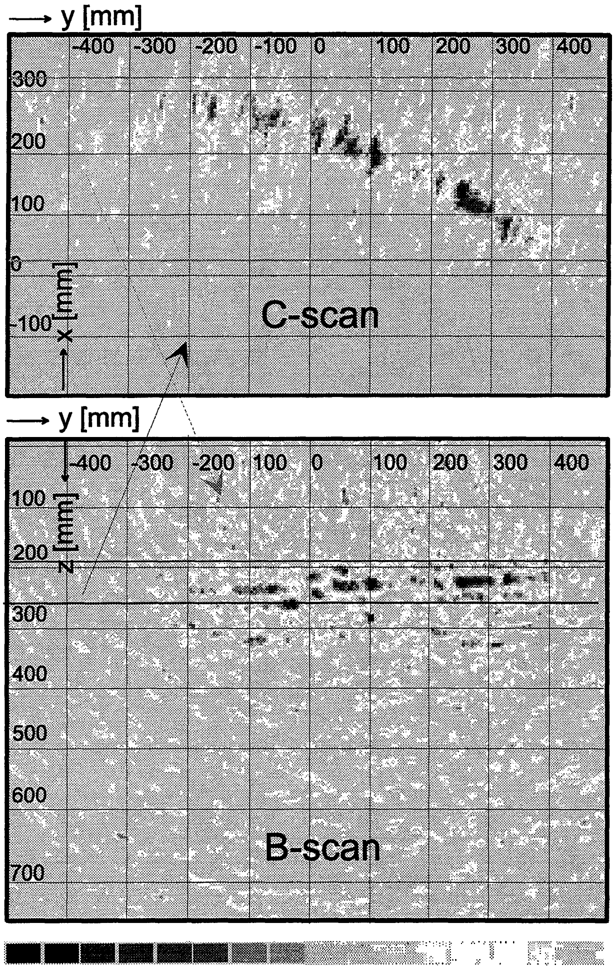


Figure 1 (left): Result of 3D-SAFT reconstruction showing a tendon duct, for details of the specimen, see Figure 7. The experiments were carried out from the back side of the specimen as shown in Figure 7.
Upper part: top view (C-scan) of the projection from a chosen depth range indicated by horizontal lines in the B-scan.
Lower part: side view (B-scan) showing the y-axis vs. depth. Reflections from the near and the lower surface of the duct are seen at ca. 230 mm and 320 mm, respectively.

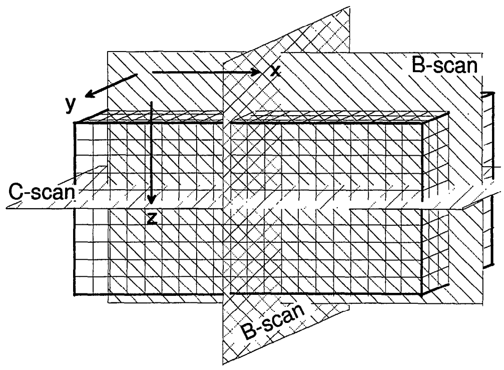


Figure 2: Principal sketch for the projection planes of the results of a 3D-SAFT reconstruction.

3 Evaluation methods and simulation of acoustic wave propagation

To get a rough idea of the geometry inside the material examined The data are evaluated by a time-of-flight-corrected technique [5].

Three-dimensional reconstruction images are obtained by the Synthetic Aperture Focusing Technique (SAFT). High-frequency echoes (HF-A-scans) from the interior of the component are registered, digitized, and superimposed in a special way. In principle this corresponds an averaging of high-frequency signals. A 3D-SAFT reconstruction method was applied for our inspections. After rectifying and filtering the three-dimensional distribution of reflections and backscatter from the interior of the tested object will be obtained [9][10].

The 3D-SAFT results are visualized as two dimensional projections from the three-dimensional reconstructions of the scattered ultrasonic waves. Figure 1 shows the reconstructed image of a tendon duct. An interpretation will be given below. In the upper part of the figure the top view of the projection from a chosen depth range of the interior of the tendon duct is shown (C-scan). The limits of the range of projection is indicated by horizontal lines. The lower part of the figure is a side view (B-scan) showing the depth of the scattering centres. The projection range of the x-axis is also indicated. As a principal sketch Figure 2 shows the reconstructed volume and the position of the planes of projection.

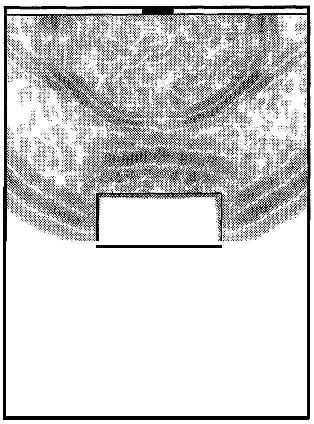
The long wavelength of about 50 mm and the lacking sharpness of the image indicates why these projections should be studied instead of sections. In addition, it should be noted that the tendon ducts are in general bent and are usually not embedded parallel to the surface.

As mentioned above the results described in this paper deal with the localization of grouting defects in tendon ducts and compaction defects around the ducts.

The EFIT-code (Elastodynamic Finite Integration Technique) has been used to model the ultrasonic wave propagation in concrete with tendon ducts of good quality and in the case of injection faults. A description of this method is given in [11].

In this example a 500 x 680 mm concrete specimen has been investigated. The base material is cement and the additives used are granitite, basalt, and plaster with a maximal aggregate size of 16 mm and a grading curve Al 6. The additives have been modelled by 260,000 ellipses varying statistically in size and orientation. A normal pressure probe with a centre frequency of 80 kHz has been used. The time history of the pulse is modelled by a raised cosine with two cycles. The probe has a diameter of 50 mm. On the one side the tendon duct has been modelled as a circle (cross section) and on the other side as a rectangle (longitudinal section). The thickness of the duct is 1 mm, the cross section of the circle is 90 mm, and the size of the rectangle is 200 mm x 90 mm.

The depth of the embedded duct is 300 mm. To identify the echo signals of the duct properly, the concrete has been simulated without any air inclusion. It has been shown [8] that there is a strong dependency between the damping of the elastic wave and the percentage of air inclusions. A two-dimensional modelling setup yields the upper limit of about 6% of air for the detectability of a reflection signal.



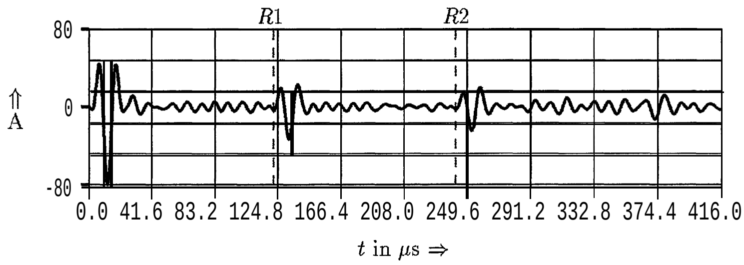
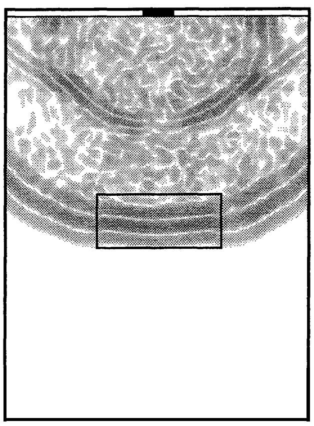


Figure 3: EFIT-simulation of an air filled duct (longitudinal section). The A-scan (above) clearly shows the multiple reflections R1 and R2 between the duct and the surface of the p-wave. The wavefronts are shown in the snapshot (left) at a time of 83.19 μs.



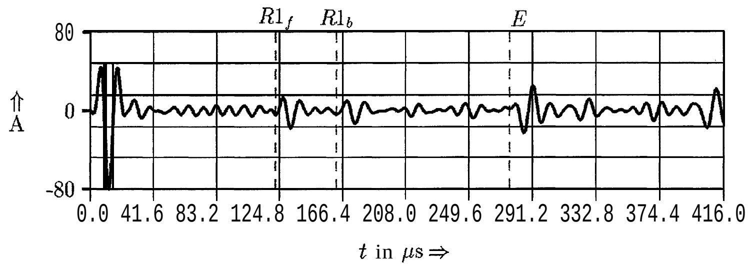


Figure 4: EFIT-simulation of a cement filled duct (longitudinal section). The A-scan (above) shows the front and back side p-wave echo ($R1_f$, $R1_b$) of the duct and the backwall echo E of the specimen. The snapshot of 83.19 μs gives an impression of the wavefront penetrating the duct

The perfectly filled duct is modelled as filled with cement, the non-perfectly filled duct is modelled as completely filled with air. Figure 3 shows a snapshot of the wavefield simulated with EFIT and the expected A-scan for a longitudinal section. The transducer is shown in all figures at the top of the wavefield. Figure 4 shows the same situation for an air filled duct. Both figures clearly show the pressure (cp) and the shear wave fronts (cs). The air filled duct shows a reflection of the duct surface (R1) only. For the cement filled duct the wavefronts travel through the duct. The respective A-scans clearly identify this fact.

The amplitude of the reflected signal $R1_f$ is significantly higher in the case of an empty duct. But the filled duct only gives an indication of the back side of the duct ($R1_b$). The scattered signals may be explained by the wave impedance of the media. Together with the size and the shape of the duct the scattered signals depend upon the difference of the wave impedance between duct and filling. A bigger impedance difference gives a bigger reflected signal. The transition from steel to air gives such a big step in the impedance profile that the incident wave is totally reflected. This is the reason why the back side of the duct cannot be detected.

Figures 5 and 6 reflect the same behaviour for the circular cross section. But the curved surface of the duct reflects less energy in direction of the receiver, and therefore the amplitude of the signal is smaller.

In conclusion the following principles may be deduced from the simulation in order to evaluate the 3D-SAFT reconstructions and to identify defects:

1. The interfaces between concrete/steel/air (empty duct) lead to higher amplitudes of reflected ultrasonic waves than the interfaces between concrete/steel/grout (filled duct).

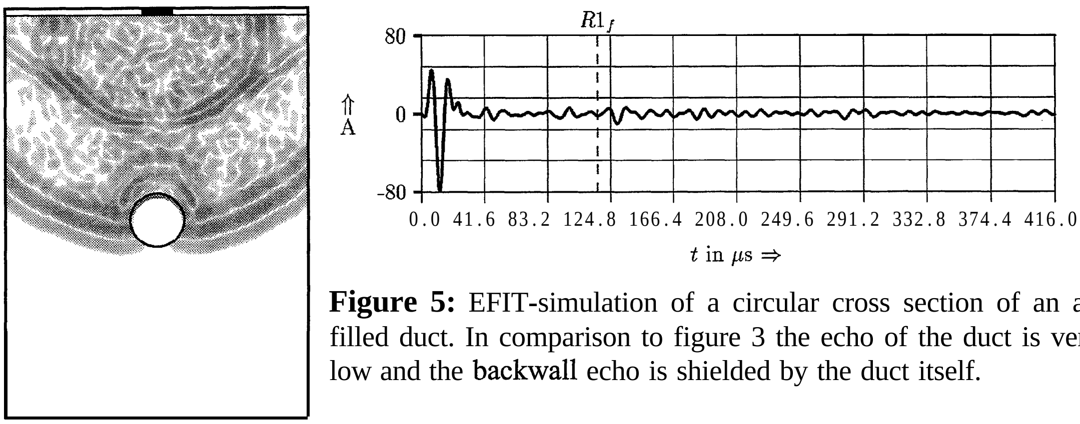


Figure 5: EFIT-simulation of a circular cross section of an air filled duct. In comparison to figure 3 the echo of the duct is very low and the backwall echo is shielded by the duct itself.

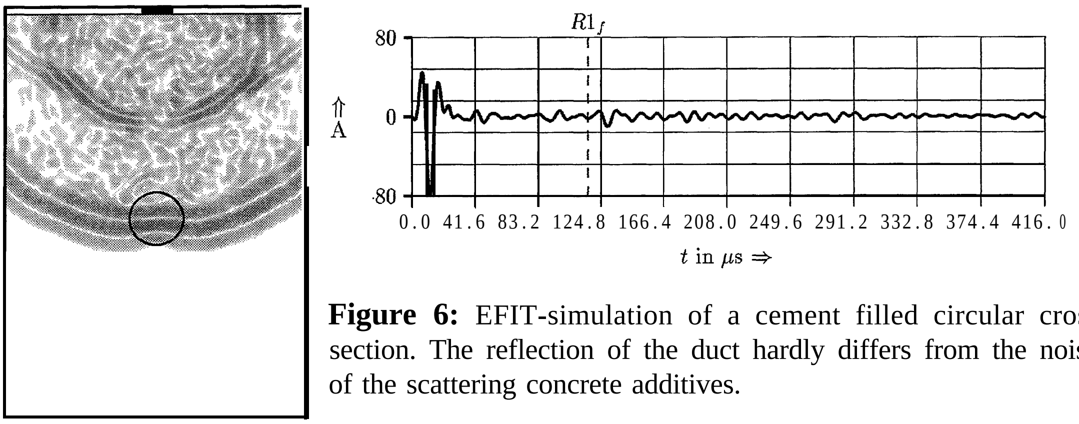


Figure 6: EFIT-simulation of a cement filled circular cross section. The reflection of the duct hardly differs from the noise of the scattering concrete additives.

2. When the ultrasonic waves travel through the interface concrete/steel/grout, the ultrasonic energy passes and partly it is reflected from the lower surface of the tendon duct. In case of grouting defects in the tendon duct no ultrasonic energy passes into the duct and therefore no image of the lower surface will be obtained.

Additionally it is assumed, that a compaction defect around the tendon duct means that there is no clear interface between the concrete and the loose aggregate. Such an area is likely to scatter the ultrasonic energy diffusely and to have a smaller amplitude than the reflection of the duct, the echo of the duct will vanish.

4 Results

We present the results obtained by a round robin test which was carried out in cooperation with the Federal Highway Research Institute (BASt). Radar and six different ultrasonic test methods, impact-echo and simulation calculations were used to compare and assess the present state of technology of these methods [5][8]. The test series were carried out as blind tests, i.e. the construction plans were revealed after the tests. In the present paper only the results are presented which were obtained by the ultrasonic method described.

The construction plan and the results are presented in Figure 7. The tendon ducts to be identified were partly embedded behind grid rebars (spaced 150 mm, diameter 12

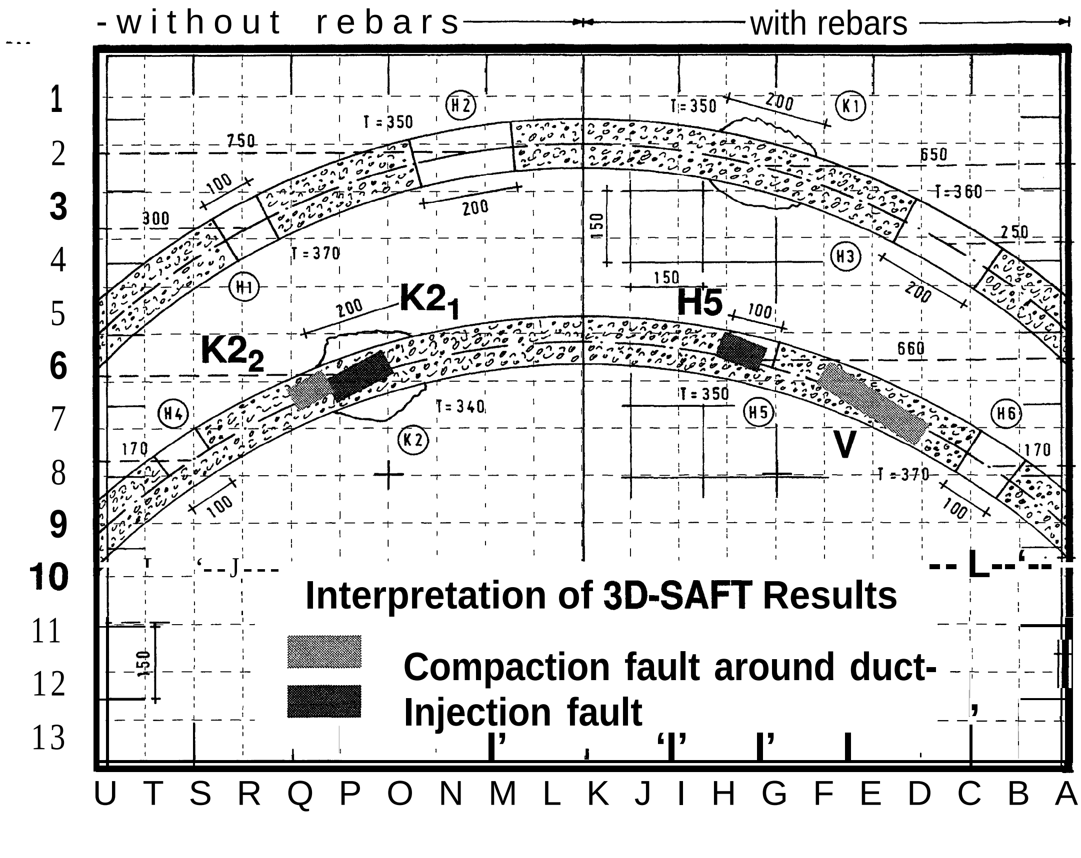


Figure 7: Construction plan for the specimen for the blind test series at BASt (dimensions in mm). Compaction faults (K) and injection faults (H) are intentionally placed around and inside the two ducts.

The grey fields indicate the location of the defects at the lower duct interpreted from ultrasonic testing. V: Compaction defect, which was not intended. The results presented in Figure 1 were measured from the back side.

mm), additionally stirrups were inserted. The lower tendon duct was scanned with the laser vibrometer at 12 different transducer positions and the defects were interpreted from the 3D-SAFT reconstruction. One void (H5) could clearly be identified and a compaction fault around the tendon duct (K2) could be detected quite accurately. However, a part of the compaction fault had been misinterpreted as a grouting defect and one not intended compaction defect was identified.

An example of the 3D-SAFT reconstruction of six measured partly overlapping areas in the part without reinforcing rebars of the test specimen is shown in Figure 1, as mentioned above (for further information refer to the references [5][8]). In the upper part of the figure the bent tendon duct can be identified (C-scan) while in the lower part (vertically to the surface, B-scan) its near surface and about 90 mm below its lower surface may be recognised.

In the upper tendon duct of the specimen the defects were measured after the construction plan was revealed and the grouting defects were additionally localized by destructive testing. Here the lower surface of the duct is not clearly detectable in the reconstruction. So the intensity of reflection was taken into account for the interpretation. In Figure 8 the C-scan obtained with the 3D-SAFT reconstruction is superimposed to the design sheet and the defects measured by destructive testing. The points of high intensity of reflected ultrasonic waves fit most of the intentionally and unintentionally placed defects.

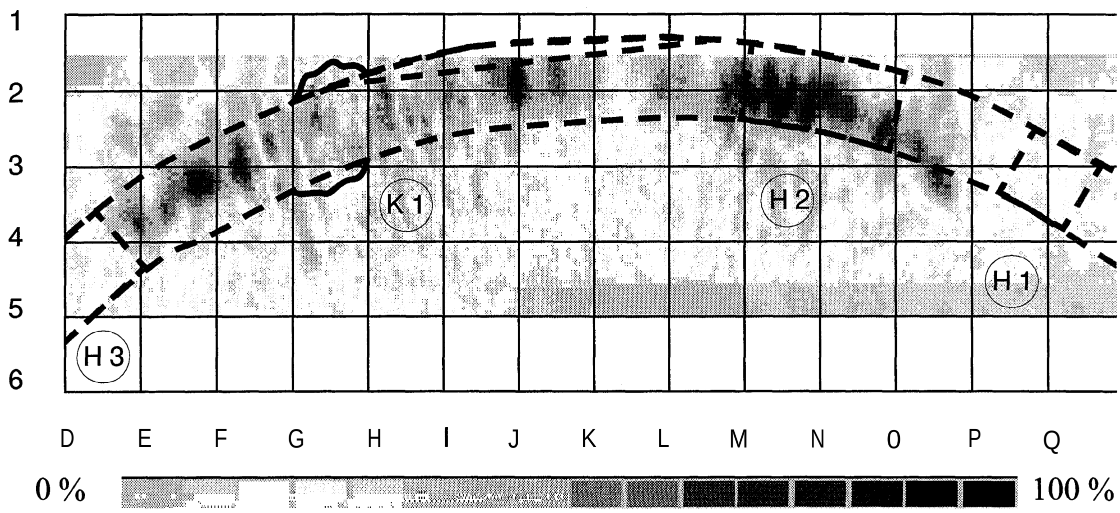


Figure 8: Result of the 3D-SAFT reconstruction at the upper duct of the test specimen of BASt, measured area from axis E to P (see figure 7). This view is shown from the opposite side compared to figure 7. The C-scan is compared with the result of destructive testing of the specimen. High intensity of reflected ultrasonic waves fit with intentionally and unintentionally placed defects.

5 Conclusions

A modification of the ultrasonic pulse echo method using the Synthetic Aperture Focusing Technique provides an imaging system for the detection of internal structural changes in reinforced concrete components. The data obtained were reconstructed by means of 3D-SAFT revealing the image of tendon ducts in concrete. The exact position of the tendon ducts and the depth of the concrete cover could be clearly detected. The method has been applied successfully on a concrete specimen of common characteristics (maximum aggregate size 16 mm, pore content 5 %, depth of the tendon duct 300 mm) and was able to work in presence of grid rebars (spaced 150 mm, rod diameter 12 mm).

From the modelling of the ultrasonic wave propagation in concrete the principles of the interpretation of the results could be deduced. The modelling was performed for the concrete admixture and the dimension of the specimen under investigation.

The good performance of this method was demonstrated in a blind test where several defects in and around tendon ducts were detected.

The high pore content of the concrete complicates the interpretation of the results, as it was also demonstrated by the modelling. It becomes evident that the localization of most of the defects is only possible using scanning systems including reconstruction calculations.

When the lower surface of a duct is not visible in a reconstruction at all, an evaluation of the intensity of the reflected ultrasonic signals is necessary. Then not all defects can, however, unambiguously be identified because the intensity differences of the signals often are not distinct enough. Work on improving the measurement technology and reconstruction calculation, as well as simulation, must be continued at this point to support the interpretation of defects.

The described results at test specimens presented in this paper show, that ultrasonic echo methods can identify important defects in post-tensioned concrete structures. It is a very useful task to develop those methods to be used for the condition assessment of engineering structures in order to assure the durability and to obtain data for the decision, whether an construction is still in a serviceable condition or not.

6 Acknowledgments

We gratefully acknowledge financial support from Federal Highway Research Institute (BASt) for the round robin tests.

7 References

1. Kroggel, O., Jansohn, R. and Ratmann, M. (1995) Novel ultrasound sysyem to detect voided ducts in post-tensioned bridges. *Proceedings of the 6th International Conference on Structural Faults and Repair*, Vol. 1, M. C. Forde (ed.) , Engineering Technics Press, London, pp. 203-208.
2. Schickert, M. (1995) Towards SAFT-Imaging in Ultrasonic Inspection of Concrete. *Proc. Int. Symp. Non-Destructive Testing in Civil Engineering Sept.* 26-28 *1995* G. Schickert, H. Wiggenhauser (eds.), DGZfP, Berlin, pp. 4 11-4 18.
3. Wollbold, F. and Neisecke, J. (1995) Ultrasonic-impulse-echo-technique - advantages of an online-imaging technique for the inspection of concrete. *Proceedings of the International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE)* G. Schickert and H. Wiggenhauser (eds.), DGZfP, Berlin, pp.1 135-1143.
4. Krause, M., Bärmann, R., Frielinghaus, R., Kretzschmar, F., Kroggel, O., Langenberg, K., Maierhofer, C., Müller, W., Neisecke, J., Schickert, M., Schmitz, V., Wiggenhauser, H. and Wollbold, F. (1997) Comparison of pulse-echo mehods for testing concrete. *NDT&E International 30,* pp. 195-203.
5. Krause, M., Müller, W. and Wiggenhauser, H. (1998) Ultrasonic Inspection of Tendon Ducts in Concrete Slabs using 3D-SAFT. *Acoustical Imaging 23,* in press.
6. Krause, M. and Wiggenhauser, H. (1997) Ultrasonic Pulse Echo Technique for Concrete using synthetic Aperture. *NDT in Civil Engineering 8-11 April 1997, Conference Proceedings,* J. H. Bungey (ed.), The British institute of NDT, Northampton, pp. 135-142.

7. Funk, T., Maierhofer, C., Leipold, S. and Borchardt, K. (1997) Non-destructive Location of Tendon Ducts in Concrete Bridges for the Installation of Noise Insulation Walls Using Impulse Radar. *Proceedings of the Seventh International Conference on Structural Faults and Repair*, Vol. 1, M. C. Forde (ed.), Engineering Technics Press, London, pp. 323-340.
8. Krieger, J., Krause, M. and Wiggenhauser, H. (1998) *Erprobung und Bewertung von zerstörungsfreien Prüfmethoden fur Betonbriicken*, BASt, Bergisch Gladbach, in press.
9. Schmitz, V., Kröning, M. and Langenberg, K. J. (1996) Quantitative NDT by 3D Image Reconstruction. *Acoustical Imaging 22*, pp *735-744*.
10. Schmitz, V. and Müller, W. (1998) Evaluation and interpretation of SAFT images. *Acoustical Imaging 23*, in press.
11. Fellinger, P. (199 1) *Ein Verfahren zur numerischen Lösung elastischer Wellenausbreitungsprobleme im Zeitbereich durch direkte Diskretisierung der elastodynamischen Grundgleichungen*, Dissertation, Lehrstuhl für Theoretische Elektrotechnik, Universitat Gesamthochschule Kassel.

Socio-Economic Changes and Sustainable Construction

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Abstract
Western industrialized countries are evolving in their approaches to governance and to economic growth. Many are moving away from a central, welfare for all, top down model to a devolved, small, less interventionist type of government. Independent firms and individuals are expected to ensure their own development. Government is limiting its activity to facilitation and catalytic role.

In that context, sustainable construction approaches and technologies need to be reviewed. Since the very definition of sustainability involves "future generations", current governance, economic and technology systems may not be adequate. The old egalitarian approach of Western democracies, as well as the new minimalist state, do not appear effective in addressing sustainability issues. The free-market capitalism has also shown many limitations in that regard. Nevertheless, in the present socio-economic system, there are opportunities for "win-win" situations, where construction, through enhanced design and technology combined with better public awareness, can achieve environmentally positive results.

Current, incremental mode of technological change requires acceleration and additional research needs to be undertaken in the areas of general modeling and assessment of constructed ecosystems as well as in the understanding of avoidance of environmental hazards, remediation and restoration.

In the face of shrinking markets for new construction in the Western industrialized countries, sustainable construction practices can represent new business as well as an opportunity to create a positive image for the industry.
Keywords: sustainable construction, evolving socio-economic forces, new business opportunities, technology and regulatory challenges

1 Introduction

World has been concerned with the sustainability issue for some time. In the 1970's, an influential international group "Club de Rome" produced a report "Limits to Growth" [1] which was based on estimates of rapidly disappearing natural resources required to sustain life on the Planet Earth. Significant, science based debate started but because of the "zero-sum" nature of the analysis and insufficient consideration of the adaptability of market forces and the potential of technological changes, this report was considered overly pessimistic.

The pressures on world's eco systems (including a number of mini-catastrophes) continued and in 1987, World Commission on Environment and Development produced the report "Our Common Future" [2], often referred to as The Brundlandt Report: It provided what is now broadly accepted as the working definition of sustainable development: "that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Thus, an alternative goal became available to economic development, with considerable interpretation difficulties of inter-generation perspective and need for long term environmental impact knowledge.

Since then, there has been growing concern about various symptoms such as widespread deforestation and desertification, greenhouse and ozone-depleting gases, pressure on arable lands, and in general, doubt that conventional policy, economy and technology approaches may be adequate to deal with the complexities of sustainability and that new approaches may have to be proposed.

The very definition of sustainable development, with its long-term view, challenges currently available scientific data as well as presently known "holistic" models of interaction between ecology, sociology, economics, policy making and technology development. However, action to reduce risk should not await scientific certainty. Precautionary principles of public policy suggest that preventive action must be initiated at early stages while more precise scientific evidence is obtained to prove causality.

There have been numerous attempts to review construction activity from sustainable perspective, particularly various processes, systems and materials. There is no doubt that construction has a very significant role in the sustainable development context:

- through its size, as a very large industrial sector, representing 10%-15% of most countries economies
- through transformation of raw and semi-processed materials and changes to environment, it creates approx. 2/3 of world's fixed assets, characterized by long life and potential for further environmental impact at the repair, demolition or re-use stage,
- it is the largest industrial source of solid waste, in Canada accounting for close to one third of the total
- it is a very significant user of energy in many countries, up to 50% of total being consumed in the operation of constructed facilities
- it is capable of environmental intrusion as well as of problem remediation, with total downstream effects not always well understood

At the present time there is considerable debate, locally, nationally and internationally as to the appropriate environmental goals and standards for most human endavours **[3].** Thus it is considered useful to review construction from the perspective of sustainable development.

It is proposed to use a "system" approach, while being aware that our knowledge of linkages between the sub-systems is incomplete and that dynamic changes are continuously taking place. Most of trends presented are based on review and knowledge of current or emerging practices in Western Europe and North America. It is not clear how such practices apply to Asian countries or to other parts of the world. Given the global diversity, we believe that generalizing our findings may be already somewhat bold and ambitious.

In the first place, we shall review changes taking place in the governance structure of many countries and underline the ever important role of government(s) in environmental matters. Then, we shall look at the market mechanisms currently in place and their ability to deal with short- and long-term factors and externalities. Scientific development has been suggested as a solution as well as a problem to many pollution situations. We shall look at the major groups of technologies that hold promise. Finally, we shall suggest to the construction industry major new business opportunities and challenges, as the world gears up to deal with its future.

2 Governance trends

As previously defined, sustainable development involves intergenerational concerns and, in many instances, transborder movement of polluting matters. Thus, one can reasonably assume that government(s) have an important role to play in defining appropriate policies and collective actions. Significant changes are now taking place in policymaking process, which are already having impact on sustainability problems and solutions.

One of the powerful policy themes of Western democracies, for a significant time, has been the egalitarianism. This philosophy, which has been at the centre of the concept of welfare state, believes that equal opportunities and rights is a desirable objective and that every citizen should be provided with an equal access to available resources, As well, it is generally agreed that there is a principle of governance that ensures the integrity of a national territory, of its resources and economy. These approaches allowed national governments to promote energy conservation in buildings, declare levels of permissible volatile matter in building materials or agree on water purity standards.

New philosophies of minimalist state, of less intrusive nature, are now being introduced in various countries, where individual citizens are expected to be responsible for their own welfare and the state intervenes only in particular situations, when certain individuals are unable to cope and require help. At the same time, there appears to be a shift from top-down entitlement or assured right approach to a devolved, locally established, need-based intervention.

In many environmental instances, such as location of solid waste disposal site, acceptance of certain construction styles or local building materials, such less bureaucratic, more direct and efficient policy making process may appear to be desirable.

How will this shift affect sustainable development policies of a broader nature is uncertain. In North America, where construction is generally under local jurisdiction there is little evidence of long term foresight at that level while more senior governments are involved in massive consultation undertakings, attempting to reconcile often contradictory environmental objectives of different parts of the country or of various vested interests.

Opinion polls, community initiatives and presence of many non-governmental organizations (NGOs) continue to indicate reasonably high level of popular support for sustainability goals. Otherwise, emerging forms of policy making seem to have increasing difficulty arriving at actual decisions, particularly when faced with complex, long term, multivariate environmental problems.

Furthermore, it is not clear how broader national and multinational issues can be resolved without governance based on egalitarian principles as well as on those protecting national integrity. Introduction and transborder movement of building products that may be environmentally harmful, preservation of certain valuable tree species, protection of shared marine sites and many other construction-related problems will require a more active role of senior levels of government.

3 Economic considerations

The actual neo-liberalism or free-market paradigm broke through around 1900, then reinforced with the Schumpeterian model and the Chicago School. The entrepreneur is considered the principal driving force in the free-market, creating business organizations, with the objective of maximizing profits. The basic assumption for creating global wealth is to let entrepreneurs get rich, by free trade, 'laissez-faire' policy and reducing barriers of any kind, then wealth being distributed by their increasing consumption of goods.

Within this context, firms and individuals have destroyed natural resources because they have benefited from doing so. We became a wasteful society and inter-generation issues have been ignored [4].

In a global trade environment, where relative position of a country or a region is determined through market mechanism, there is an uneasy relationship between the cost of protection of the environment, particularly for future generations, and shorter-term economic benefit. Some suggest that market forces, as they are applied at the present time, do not adequately represent the "externalities" of the environment and even less so of the future considerations, hence the need for extra-market intervention mechanisms such as polluter fees, carbon taxes or regulations.

> "Capitalism offers immense dynamism, but markets do not regulate themselves. No policy is also a policy. Globalization does not invite an era of laissez-faire, but a thornier set of questions about governance." [5]

However, in most construction-related matters, assumption can still be made of "win-win" situations. Through better information on impacts, improved analysis and enhanced technology, facilitating market forces, combined with greater public awareness of sustainability, systems can emerge which demonstrate benefits exceeding costs for the short as well as for the inter-generation development [6].

Construction industry, amongst others, has often expressed concern with stringent environmental regulations and controls, stating that they affect its price performance within domestic markets and leaves it exposed internationally to unfair competition by certain countries where laws and/or enforcement may be more permissive. Large, European and American commodity-type producers of cement, steel, dimensional lumber and other building materials have argued that regulations impose significant business costs, diminish productivity and reduce their ability to compete successfully in global markets where certain firms can operate from "pollution havens" with lax controls and/or enforcement.

Studies of relative international competitiveness by Porter [7] and others suggest the contrary. There is evidence that very demanding domestic markets (including tough environmental protection measures), cause companies to improve their internal production and quality assurance processes and to upgrade their technology which eventually leads them to become more efficient in the use of resources. Thus they are able to develop world class products at lesser cost while achieving decreased environmental impact. Examples exist of no-discharge forest product manufacturers or of zero-waste steel fabricators that operate in high wage areas with demanding regulatory regimes yet are commercially flourishing.

These "win-win" scenarios, appear to be particularly successful under the following circumstances:

- companies or industrial sectors are technologically fit and they have research infrastructure and knowledge base which allows them to explore various innovative alternatives
- regulatory regime is of a flexible, performance nature, which allows the development of cost effective solutions rather than a narrow prescriptive standard type, which often forces expensive compliance
- customers are demanding and knowledgeable, asking for quality and performance.

Local decisions by industrial organizations are also of great importance to construction enterprises, which predominantly have local or regional focus. These decisions, after all, create direct building opportunities, which then amplify through local construction markets. In many countries, construction industry associations have been known to lobby against various sustainability measures on the grounds that these may reduce the economic growth and thus building activity. At the present time there does not appear to be satisfactory evidence that this is the case, furthermore such position may be contributing to the negative public image of the industry.

Well respected IMD of Lausanne produces annually The World Competitiveness Report based partially on surveys of senior executives, in order to obtain a blend of "hard" (numerical) and "soft"(opinion) based indicators. Recently, executives of large Western industrial enterprises, when asked to evaluate various input factors, were only mildly concerned with the relative stringency of environmental regulations [8].

4 Technology development

Significant opportunities exist to better manage construction resources but it is through increased knowledge and greater use of technology that the industry is likely to make advances in the context of sustainable development.

U.S. National Science and Technology Council [9] defined environmental technology as a 'technology that advances sustainable development by reducing risk, enhancing cost effectiveness, improving process efficiency, and creating products and process that are environmentally beneficial or benign"

Two large categories of technology development appear to be necessary:

- **Modeling/Assessment Techniques:** creation of realistic, long-term, multidisciplinary models of ecological systems, development of monitoring tools and of performance assessment techniques. Our present knowledge of "cradle-to-grave" behavior of building materials or of infrastructure requirements for an urban agglomeration is very limited. Furthermore, long term approach involves development of "organic construction" that can take into consideration short term needs as well as facilitating renovation to respond to future needs. A higher client satisfaction also involves an integrated approach for better homes or work spaces, easier transportation modes, access to recreation facilities, including fragile "wilderness" areas, and all the wants and needs of our consumer oriented society. In-process monitoring technology is also required, to replace the "end-of-the-pipe" approach with an "early warning" system. Ideally, on-line models would generate continuous stream of information that would allow building practitioners to adjust the construction process for the optimal outcome.
- **Avoidance, Remediation and Restoration:** development of technologies that will reduce creation of environmentally harmful materials, systems or processes (such as use of non renewable resources, harmful waste and pollution); increase recycling and re-use of materials; and facilitate remediation of ecosystems that have been negatively impacted in the past. For example, improved knowledge is needed of adverse impacts of substances on indoor air quality, of further improvements to energy conservation of building envelopes or, of increased recycling opportunities for demolition products.

New technological approaches are gradually being introduced to the industry but much of existing research results remain to be diffused, transformed into commercially viable technologies and put to practice

It is unlikely that there will be a single, large technological breakthrough that will transform the construction industry and make it environmentally compatible. Resistance to change by the industry and by its customers suggests that the present incremental modification of technology processes in waste management, of energy and water conservation, of recycling of materials and land, is correct but it requires acceleration, combined with greater public awareness.

5 Ecobusiness opportunities

Projections for Western industrialized countries indicate relatively low overall economic growth, in the range of 2%-3% per annum, and demographic trends of aging population. Since these are the principal demand factors for the industry, it may be expected that the domestic needs for construction, particularly for new facilities, will remain low.

On the other hand, there is great accumulation of existing buildings and civil works that require repair, rehabilitation and upgrading. Many of these projects were built under less stringent environmental regulations and their owners now face requirements of remediation to achieve healthy environment or legal liability, sometimes at criminal level.

Overall, direct costs of environmental compliance are expected to be very high and there has been some reluctance by all stakeholders to apply pressure for immediate action, nevertheless business activity in this sector has been gradually increasing. Various decisions at the regional, national and global levels regarding reduction of emissions, conservation of resources or creation of environmentally compatible projects have consequences on the construction industry.

Major markets have now been opened for designers, contractors and material suppliers and a great opportunity has been created to change the historical image of the industry, from environmentally intrusive to one of the builder of sustainable environment.

6 Challenge

Implementation of sustainable construction will not be easy.

> "Future development undertaken in an environmentally and economically sustainable manner requires new ways of thinking in planning, designing, building, operating, and maintaining the built environment." [10]

Moreover, sustainable development involves a systemic and holistic approach that appears difficult to achieve in the construction industry. This sector is highly fragmented, consisting of numerous small firms, suffering from a low co-operation culture among participants.

Governments will also have a crucial and far than obvious role to play in promoting promising technologies and developing performance based and flexible standards, with effective consensual processes involving numerous different stakeholders in the country, as well as internationally.

References:

1. D.H. Meadows (1972) *The Limits to Growth*, Universe Books, N.Y.
2. World Commission on Environment and Development (1987) Our *Common Future*, Oxford University Press, Oxford
3. U.K. Parliamentary Office for Science and Technology (1997) *Sustainable Development-Theory and Practice*, House of Commons, London
4. Hawken, P. (1997) Natural Capitalism, *Mother Jones*, March/April, pp.40-62
5. Kuttner,R. (1997) What the Free Market Can't Fix, *Business Week*, Nov. 17th, p. 30
6. Public Works and General Services Canada (1997) *Sustainable Development Strategy*, Ottawa
7. Porter, M.M. (1990) *The Competitive Advantage of Nations*, The Free Press, N.Y.
8. Panayotou, T., Vincent, J.R. (1997) *You Can* be Keen and Green, *World Link*, July/August 1997

9. U.S. National Science and Technology Council (1994) Strategy for *Environmental Technologies,* Government Printing Office, Washington, D.C.
10. Civil Engineering Research Foundation (1996) *Creating the 21st Century through Innovation – Engineering and Construction for Sustainable Development",* Executive Report, CERF Report #96-5016.E, Washington, D.C.

Action of gypsum on recycled aggregate concrete

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Abstract

The risk of sulphate attack and ettringite formation is the main reason to limit the use of recycled aggregate in concrete. In fact, French standards exclude any possibility of use of recycled aggregate in concrete, restricting the sulphate content of aggregate for concrete to 0.15% by mass. On the other hand, the RILEM recommendation TC 121 DRG allows concrete to contain recycled aggregate containing up to 1% sulphate by mass. In these conditions, it seems important to evaluate the action of gypsum on recycled aggregate concrete and to appraise by tests if a threshold of sulphate content exists for the recycled aggregates over which concrete expansion becomes critical and mechanical strength diminish.

In this study, mechanical strengths, expansion measurements and mass controls of concretes prepared with recycled aggregates, more or less polluted by gypsum, were compared with those of natural aggregate concrete. Various amounts of gypsum were added to mortars prepared with recycled or natural aggregates and the physical and mechanical characteristics were evaluated up to 3 months of age for specimens cured in fully immersed conditions. The results obtained show that the substitution of natural aggregate by recycled aggregate in a concrete mixture having a constant water-cement ratio and workability, produces a more or less significant decrease in the compressive and tensile strength. The decrease in strength depends on the grading of the recycled aggregate and, to a lesser extent, on the origin of the raw material. The decrease in mechanical strength is more significant when fine recycled aggregate is used in the mixture.

Concerning the effect of sulphate content, the results enable us to conclude that recycled aggregates containing 0.3 to 0.8% by mass of SO_3 do not produce a significant effect on the mechanical strength and the expansion of concretes and mortars because the most part of sulphates are coming from the cement hydrates of the raw material. Only when recycled aggregates contain significant amounts of gypsum impurities (> 1% by mass) does the strength decrease. Gypsum impurities have a more significant effect on expansion of mortars prepared with natural aggregates.

Furthermore, the results show that when recycled aggregate contains more than 0.5% by mass of additional SO_3, the expansion of mortars becomes critical. When portland cement containing lesser amounts of C_3A is used in the mixture, the additional sulphate content in recycled aggregate has to exceed 1.2% SO_3 by mass for critical expansion.
Keywords: Recycled aggregate, gypsum, sulphate content, concrete, mortar expansion, mechanical strengths.

1 Introduction

Because of the lack of development of selective demolition processes in France and the difficulties to control the origin of demolition wastes arriving to recycling plants, recycled aggregates can be more or less polluted by gypsum, the gypsum usually coming from building partition-walls and plasters. Severe expansion and cracking of concrete due to ettringite formation is considered as one of the most important pathological factors related to the use of recycled aggregates in concrete.

The French standard NF P 18 541 limit the sulphate content of aggregates for concrete to 0.15% by mass of SO_3 [1] and hence, limit the use of recycled aggregates only as an untreated by hydraulic binder sand or gravel used in banking and in sub bases of minor roads. On the other hand, the RILEM recommendation TC 121 DRG permits concrete to contain recycled aggregates containing up to 1% by mass of SO_4 [2].

In these conditions, it seems important to determine using tests, if there exists a threshold for sulphate content for these recycled aggregates over which concrete expansion becomes critical and mechanical strength diminish. Firstly, concretes prepared with recycled aggregates containing more or less gypsum impurities were compared with natural aggregate concrete. Secondly, various amounts of gypsum were added in mortars prepared with recycled or natural aggregate. Physical and mechanical characterisations, expansion measurements and mass controls up to 3 months were made for specimens cured in underwater conditions.

2 Materials

2.1 Recycled and natural aggregates

Two types of demolition wastes were selected for recycling :

- reinforced concrete structures and cement or blast furnace slag treated road bases without significant gypsum impurities,
- building demolition wastes containing concrete and masonry polluted by gypsum.

For the first part of the study concerning concretes, a 0/5 mm fine aggregate and a 5/25 mm coarse aggregate were prepared with both types of wastes, named respectively CRF05 (fine aggregate obtained from recycling of concrete), CRC25 (coarse aggregate obtained from recycling of concrete), BRF05 (fine aggregate obtained from recycling of building demolition wastes) and BRC25 (coarse aggregate obtained from recycling of building demolition wastes). Both demolition wastes were crushed and screened in the same conditions in order to guarantee the same grading for the recycled products. A natural siliceous sand 0/5 mm and a natural siliceous gravel 5/25 mm, designated NF05 and NC25, having similar grading to the recycled aggregates, were also used in the tests.

For the second part of the study involving mortars, the recycled fine aggregates, designated CRF05 and BRF05, were used. The recycled coarse aggregates CRC25 and BRC25 were further crushed to a 0/5 mm fine aggregate and named CRC05 and BRC05 respectively according to their origins. Various amounts of gypsum coming from partitions walls were crushed at the same grading (0/5 mm) and added to the fine aggregates. The natural siliceous sand NF05 and a calcareous filler 0/600 μm were also used for the mortars.

2.2 Cements and superplasticizer

Three types of cement were used for concretes and mortars according with the French standard NF P 15 301:

- a high strength portland cement CPA 55 HTS with low C_3A content,
- a rapid high strength portland cement CPA 55R CP2 with high C_3A content,
- a ordinary blended portland cement CPJ 45 with high C_3A content.

In order to obtain fixed water/cement ratio and workability for the mixtures, a polyvinyl naphthalene sulphonate based superplasticizer was added in various amounts.

3 Tests

3.1 Concretes

From a ordinary concrete mixture containing natural aggregates (NF05 and NC25) and CPJ 45 cement, we obtain by volume substitution of the fine and coarse aggregate, six new concrete mixtures containing recycled aggregates (Table 1).

Table 1**: Concrete **compositions.

Composition kg/m³	*NF/NC*	*NF/CRC*	*CRF/NC*	*CRF/CRC*	*NF/BRC*	*BRF/NC*	*BRF/BRC*
CPJ 45	299	303	300	297	304	301	302
NF05	792	825			790		
NC25	1029		981			1027	
CRF05			677	690			
CRC25		874		885			
BRF05						642	659
BRC25					827		820
Absorbed water		32	45	87	51	44	109
Mixing water	206	212	203	208	199	206	197
Superplasticizer			1.5	3		1.5	3
Apparent density	2325	2245	2205	2170	2170	2220	2090
Slump (cm)	15	15	15	14	15	14	16

Before mixing, the recycled aggregates were wetted near their total free-water absorption capacity. The absorbed water by the aggregates was considered separately from the mixing water, because it does not participate in workability of fresh concrete nor cement hydration. Various amounts of superplasticizer were added in the mixtures in order to maintain a constant water/cement ratio and slump. Compressive strength and splitting tensile strength were measured on moist air cured 0 16x32 cm cylinders at 7 and 28 days age. Expansion and water absorption were measured on underwater cured 7x7x28 cm prisms until three months of age.

3.2 Mortars

A method close to that applied for the concrete mixtures was followed for the preparation of mortars. From a ordinary mortar mixture containing natural fine aggregate (NF05), filler and cement (CPA 55 HTS, CPA 55R CP2 or CPJ 45), we proceed at a volume substitution of the natural fine aggregate using the four recycled fine aggregates (CRF05, CRC05, BRF05, BRC05) previously wetted to their total free water absorption capacity. The cement content of the mortars was fixed at 350 ± 10 kg/m^3. An amount of 1% by cement mass of superplasticizer was added to the mixture. The mixing water was adjusted to obtain a constant workability (4 ± 1 s on the LCL « maniabilimeter » French standard NF P 18 452). This fist series of mortars was comprised of fifteen different compositions.

A second and third series of fifteen mortar compositions were prepared in the same conditions than the first series by adding an sufficient quantity of crushed gypsum from partition-walls in order to obtain 0.5 and 1 .O% of additional SO_3 by mass of dry aggregate.

Compressive strength and flexural strength were measured on moist-air cured 4x4x16 cm prisms at 28 days. Expansion and water absorption were measured on 4x4x16 cm prisms cured in underwater conditions until 3 months of age.

4 Results and discussion

4.1 Characterisation of recycled aggregates

French standards for concrete aggregates were used for the physical and chemical characterisation of the fine and coarse recycled aggregates. The values obtained are shown in Table 2.

Table 2 : Physical and chemical characteristics of recycled aggregates.

Aggregate	*CRF05*	*CRG25*	*BRF05*	*BRC25*	*CRC05*	*BRC05*
Dry density (kg/m^3)	2155	2230	2265	2090	2315	2305
Wet density (kg/m^3)	2290	2360	2410	2245	2385	2430
Absorption coefficient (%)	6.3	5.5	6.3	7.5	3.0	5.4
Total porosity (%)		12.8		21.1		
Fineness modulus	3.2	2.2	3.1	2.7	3.2	3.3
D 50 (mm)	1.2	11.7	1.2	12.5	1.4	1.5
Fine particles (< 80µm %)	5.1	1.3	7.6	1.2	6.7	8.5
SO3 content by mass (%)	0.56	0.38	0.78	0.74	0.38	0.74
Cl content by mass (%)	0.04	0.04	0.03	0.02	0.04	0.02
-C- content by mass (%)	1.28	0.75	0.26	0.14	0.75	0.14

We can observe that the physical and chemical characteristics of recycled aggregates depend on origin of the waste. Recycled aggregates obtained from concrete and hydraulic binder treated materials (CRF05 and CRC25) increase in density as the particle size of the aggregate increase. The inverse is true for recycled aggregates derived from building demolition wastes (BRF05 and BRC25). In both cases, secondary crushing of coarse aggregate seems to improve the physical properties and to increase the dry density (CRC05 and BRCOS). Except the fine recycled aggregate obtained by secondary crushing of reinforced concrete and hydraulic binder treated materials, the absorption capacity of recycled aggregates is higher than the thresholds fixed by the French standards, according to which the absorption coefficient must be lower than 5%.

The sulphate content of aggregates coming from building demolition wastes is higher than that of aggregates coming from reinforced concrete and cement treated materials due to the presence of gypsum impurities observed in the raw materials before crushing. We determined by X ray diffraction that about half the sulphate content of building demolition wastes is present as gypsum. In this case, the sulphate content of concrete and cement treated material seems to be rather important. We surmised that the presence of blast furnace slag as binder in the raw material is the principal reason for this value. In both cases, the sulphate content remains much higher than that fixed by the French standards as the limiting value for concrete aggregates (0.15%). On the other hand, the organic compounds content is more important in the fist type of recycled aggregates because of the presence of some bitumen treated aggregates mixed with the road demolition materials.

4.2 Study of concretes

The mechanical characterisation of concrete mixtures with and without recycled aggregate at 7 and 28 days show that natural aggregate concrete in general provides the higher strengths (Figures 1 and 2). The decrease of strengths by the insertion of recycled aggregate in concrete mixture is lower only when coarse recycled aggregate is used (NF/CRC and NF/BRC). In this case, the decrease varies between 0 and 25%, the mean value is about 15%. On the other hand, when fine recycled aggregate is used, the decrease in strengths varies between 20% and 40% with a mean value about 30%. The measured decrease in strengths is slightly more significant only if fine recycled aggregate is added (mixtures CRF/NC and BRF/NC).

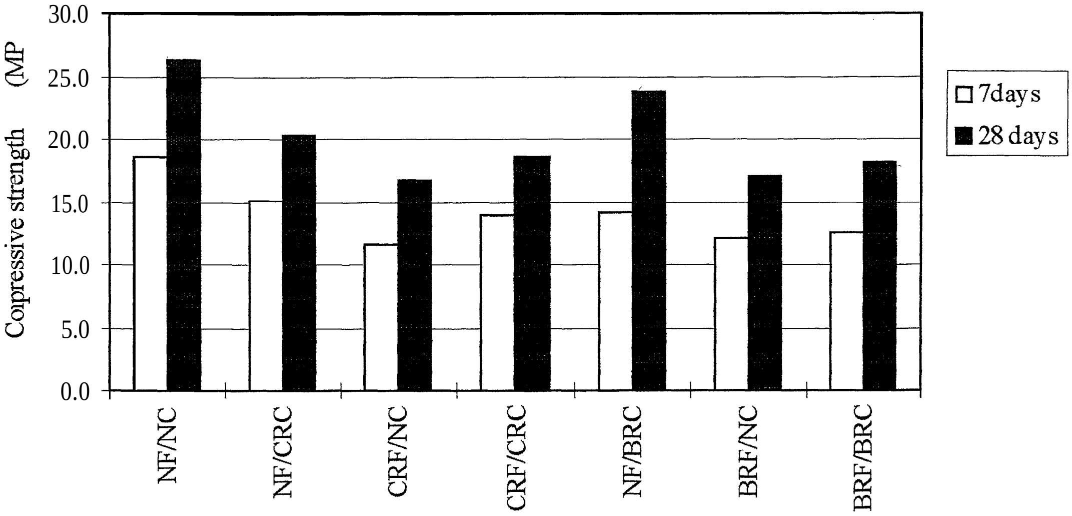

Figure 1 : Compressive strength of concrete mixtures at 7 and 28 days age.

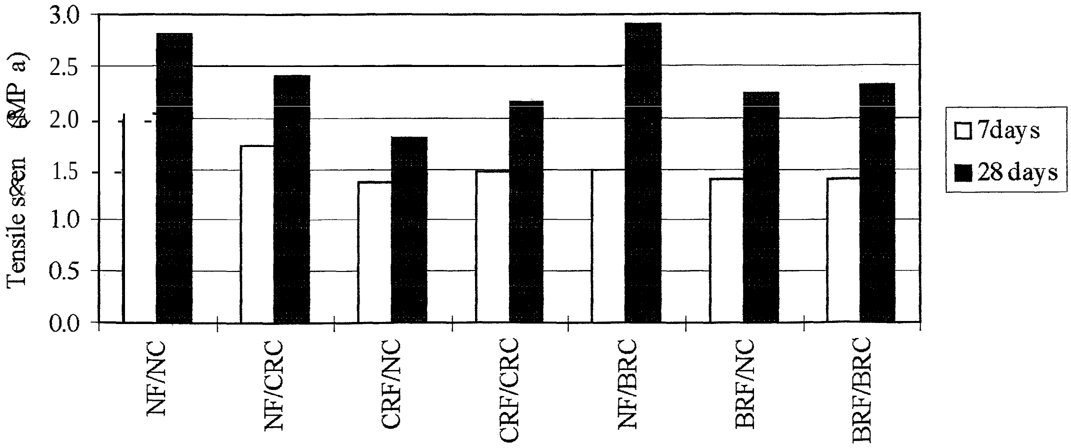

Figure 2 : Splitting tensile strength of concrete mixtures at 7 and 28 days age.

The origin of recycled aggregates does not significantly influence the mechanical strengths. In fact, the fine recycled aggregates provide concrete mixtures with nearly the same mechanical characteristics regardless of their origin. Only the coarse recycled aggregate coming from building recycled wastes, when inserted alone, gives higher quality concrete than that obtained using coarse recycled aggregate derived from recycled concrete structures in spite of its lower dry density and its higher absorption capacity.

In all cases, the presence of small amounts of gypsum in the building recycled wastes has not any obvious disadvantageous effect on mechanical strengths.

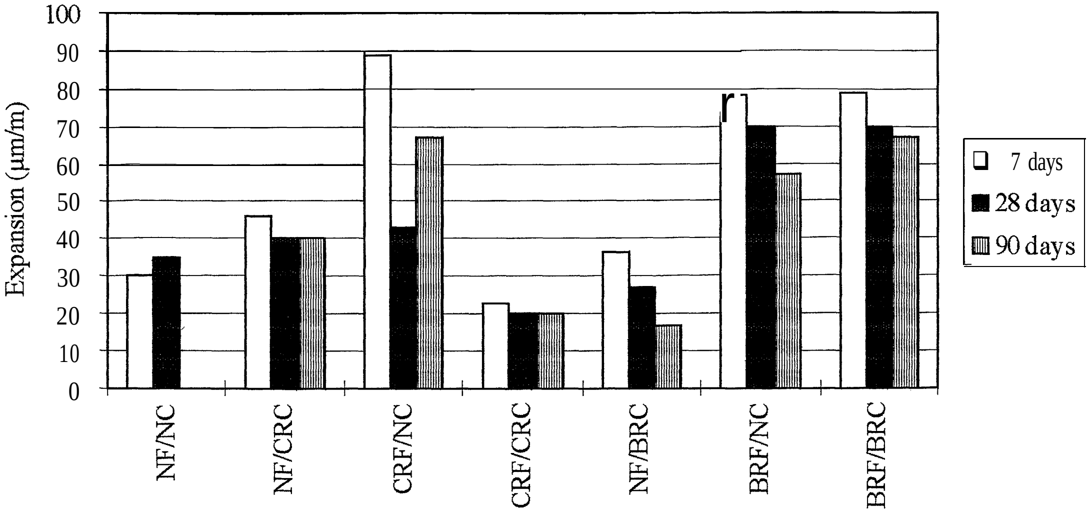

Figure 3 : Expansion of underwater cured 7x7x28 cm prisms until three months age.

The expansion measurements up to 90 days of age on specimens cured in underwater conditions (Figure 3) show that for the different concrete mixtures the values fluctuate between 20 and 90 µm/m. Mixtures with fine recycled aggregate seem to present higher expansion than that measured with natural aggregate or coarse recycled aggregate. But in any case, the expansion values are manifestly lower then 200 µm/m considered as the critical threshold for cracking.

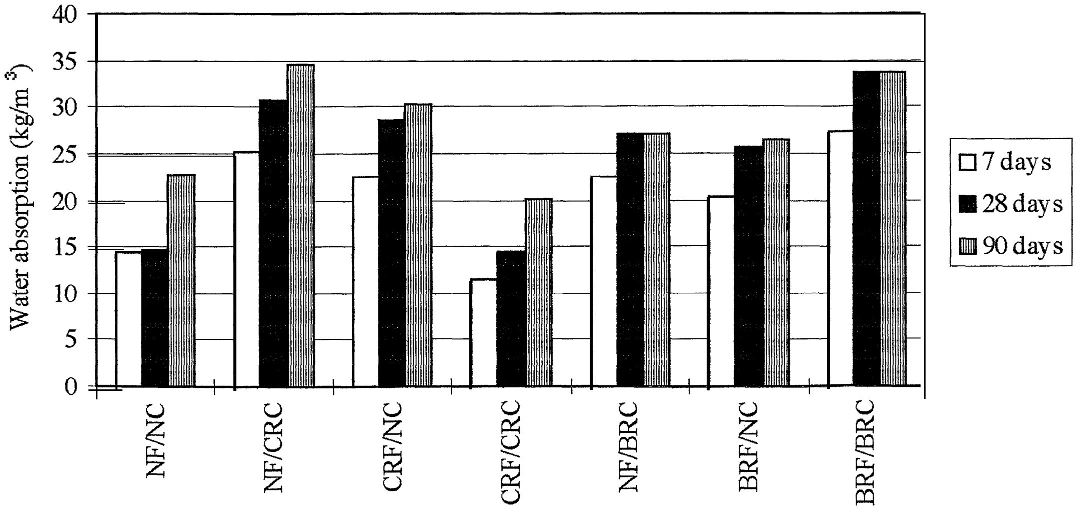

Figure 4 : Water absorption of underwater cured 7x7x28 cm prisms until three months age.

Water absorption of the recycled aggregate concrete mixtures is limited at usual values for concrete, between 10 and 35 kg/m^3, and never reach important thresholds (Figure 4). The values of water absorption are consistent with those of expansion and permit concluding that no significant amount of expansive ettringite is formed in concrete with recycled aggregate when its total sulphate content is limited to 0.8% even if a part of sulphate content (up to *50%)* contained as gypsum. The results also permit to observe that, when recycled aggregates are effectively wetted before -mixing, the resulting concretes are practically saturated and free water absorption remains low.

4.3 **Study of mortars**

Figures 5 and 6 present the variation of the compressive and the flexural strength of mortars as a function of the total sulphate content coming from recycled aggregates and added gypsum expressed as a mass percentage

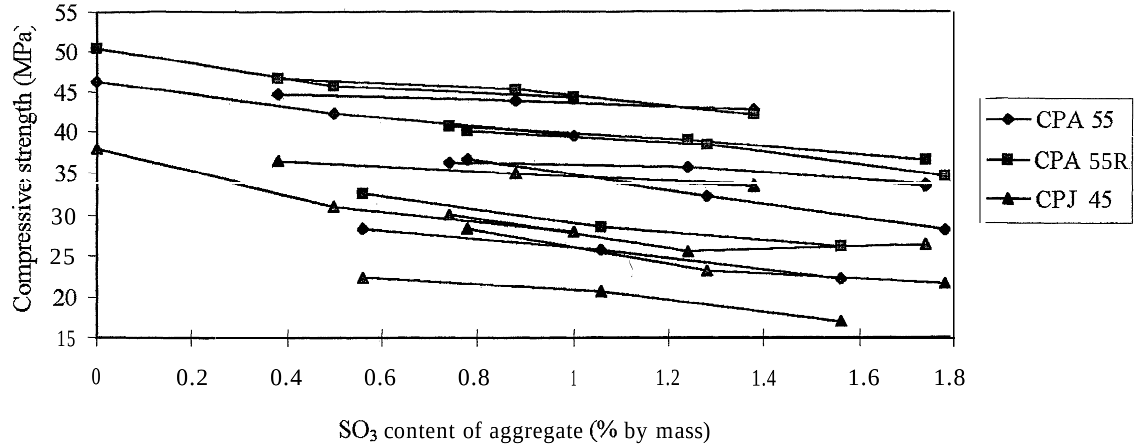

Figure 5 : Compressive strength of mortar mixtures at 28 days age as a function of sulphate content and cement type.

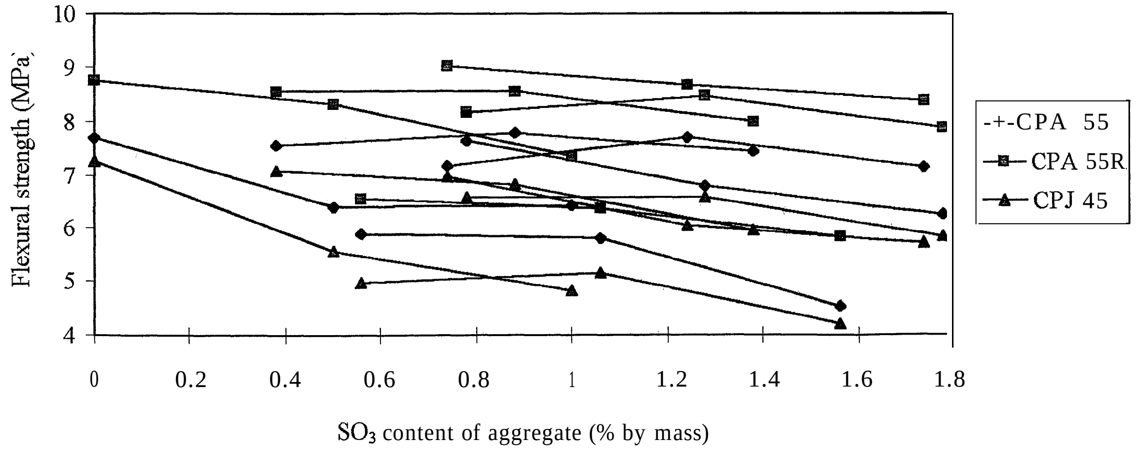

Figure 6 : Flexural strength of mortar mixtures at 28 days age as a function of sulphate content and cement type.

We can observe that the mechanical strength of mortars decreases in proportion to the sulphate content of aggregates. Among natural, sulphate-free aggregate and recycled, high sulphate content aggregate, the compressive strength could be reduced between 20% and 35% and the flexural strength between 10% and 40% depending on the type of cement used in the mix. For a fixed amount of sulphate content the mechanical strengths vary according to the physical properties of the aggregate as it was previously observed in the case of concretes.

The measurements taken at 90 days show that the expansion of mortars is closely correlated with the sulphate content of aggregate (Figure 7). In fact, the critical threshold for cracking of 200 µm/m is reached in the case of blended, high C_3A content cement (CPJ 45) mixed with natural aggregates when the sulphate content is 0.5% by mass. The sulphate content must be higher than 1 .O% if portland cement with low C_3A content (CPA 55) is mixed with natural aggregate. Recycled aggregate mortar expansion is significantly lower than that observed for natural aggregate mixtures. The critical expansion threshold is reached for more than 1.2% sulphate content, except the case of blended, high C_3A content cement (CPJ 45) mixed with secondary crushing reinforced concrete wastes (CRC05), which physical properties are close to those of the natural aggregate.

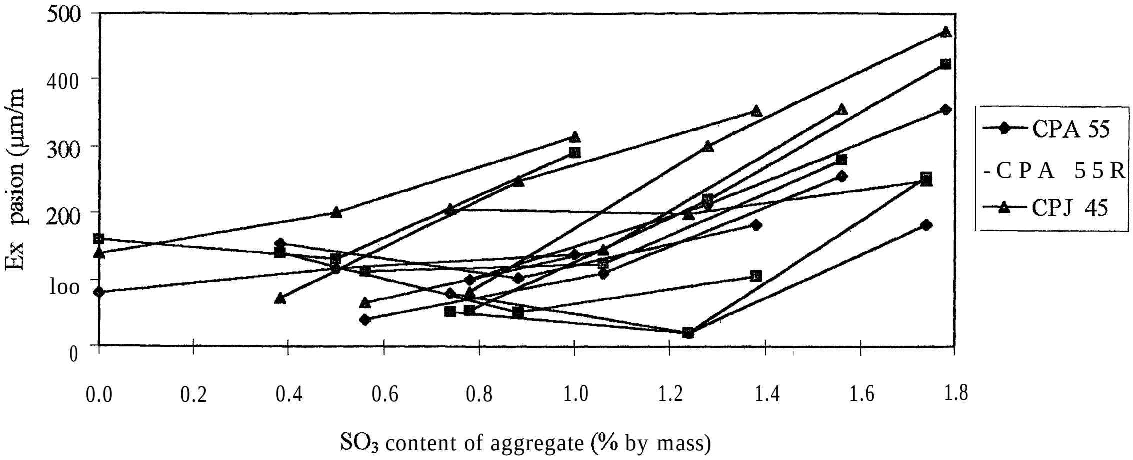

Figure 7 : Expansion at three months age of underwater cured 4x4x16 cm prisms of mortar as a function of sulphate content and cement type.

5 Conclusion

The results obtained enable us to conclude that recycled aggregates, derived from reinforced concrete structures, hydraulic binder treated road bases, masonry and building wastes, contain significant amounts of sulphate (0.3 to 0.8% by mass of SO_3) that are combined in cement hydrates that do not produce significant expansion of concretes or mortars. Mortars expansion becomes critical only when recycled aggregate contains at least 0.5% of additional SO_3 by mass, typically found from gypsum impurities (plasters and partition-walls). The additional sulphate content of recycled aggregate could exceed 1.2% SO_3 by mass when low C_3A Portland cement is used in the mixture. In a general way, gypsum impurities have more effect on expansion of mortars prepared with natural aggregate. On the other hand, compressive and flexural strength of mortars decrease in proportion to the sulphate content.

6 References

1. AFNOR (1994) Granulats pour bétons hydrauliques, NF P 18 541
2. RILEM TC 121 - DRG Recommendation (1994) Specifications for concrete with recycled aggregates, *Materials and Structures*, Vol. 27, pp. 557-59.

Recycled Waste Clinker X-ray Structural Analysis

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Abstract
Environmental protection policy and economic reasons brought about a sharp rise in the utilization of industrial waste in the manufacture of construction materials. But recycled waste can be a source of allergic, toxic, radioactive, carcinogenic, and other dangerous substances. Besides, technical process of waste recycling can be unstable.

To make the production of construction materials out of waste products ecologically safe and economically reasonable, it is necessary to provide a complete and thorough inspection of the chemical and phase composition of the components and products used. For this purpose an X-ray structural analysis of solid waste and sludge of chemical production has been performed to determine their mineralogical composition, physical and mechanical properties; and on this basis the composition of the raw materials mixture for Portland cement production has been developed.

The chemical composition of the waste was determined through an X-ray spectrum analysis; and the phase composition of both the waste used and cement clinker obtained was determined by using an X-ray diffractometer in the Cu **-** Ka emission range. Physical and mechanical tests of the cement stone samples were conducted in accordance with standard procedures.

X-ray investigations ascertained the possibility of using solid waste of chemical production in the production of construction adhesive materials. It is proved that dumped self-slaked lime, neutralized sludge of lime after chemical purification, and of diethylbenzol production sludge can be used for production of Portland cement of the usual mineral-containing composition.

Composition of the raw materials mixture, data of the X-ray analysis of the mineralogical composition of the clinker obtained, the results of physical and mechanical tests of Portland cement are provided.

Key words: X-ray method, phase composition, diffractography, solid waste of production, Portland cement.

1 Introduction

Natural resources saving and industry blow-out reduction have brought out a sharp rise in amount of the secondary resources in the manufacture of construction materials thus promoting the solving of economy and ecology problems. But in this case allergic, toxic, radioactive, carcinogenic and other harmful substances can get into construction materials and items with the recycled waste. The technological process can be of unstable character. Chemical and phase compositions of initial components and products are to be analyzed totally and thoroughly in order to substantiate the ecological reliability of the recycled waste and to reduce the energy, labor and material expenditure when the production technology is made and construction structures are operated. For this the modern methods of physicochemical analysis are used.

We conducted X-ray structural analysis of solid waste and sludge (taken from dumps and storage ponds of chemical production). On their basis we worked out the compositions of raw material mixture for Portland cement. We determined the composition of the Portland cement and its physical and mechanical properties.

2 Methodology

The phase composition of the investigated waste and of the obtained cement clinker was determined by the DRON-3M X-ray diffractometer (Russia) in the Cu-Kα emission range. The samples for diffiactography were prepared in cuvettes packed with powder.

The chemical composition of the investigated waste was determined by X-ray spectrum analysis with the CPM-25 instrument (Russia).

Physical and mechanical tests of the cement stone samples were conducted in accordance with the working standard procedures in Russia.

3 Discussion

Waste of self-slaked lime, neutralized sludge of lime after chemical purification of water, and of diethylbenzol production sludge can be used as initial raw materials to Portland cement of usual mineral-containing composition. Diffractography of the mentioned waste is given in Fig. 1 and 2. Diffractographies of the tested samples of the self-slaked lime and neutralized lime (fig. 1) show the clear-cut phases of $CaCO_3$, $Ca(OH)_2$, SiO_2. Presence of calcite, calcium hydroxide and quartz phases only indicates the possibility to replace the carbonate rock by the above mentioned waste for production of clinker.

Diffractographies of sludge of lime after chemical purification of water (fig. 2, curve 3) show the phases of $Fe_2O_3, Fe_3O_4, CaCO_3. SiO_2; Ca(OH)_2$ is detected by the reflex 2,63Å. Analysis of diffractographies of diethylbenzol production sludge (fig. 2, curve 4) shows that the main phases of the tested samples are Al_2O_3, Fe_2O_3 and SiO_2. As appears from the phase composition investigations the mentioned waste can be used instead of argillaceous rock containing aluminum oxide, silica and ferric oxide.

Thus raw materials mixture for clinker production can be made out of the investigated waste without using natural resources.

Average chemical composition of the investigated waste is given in Table 1.

Calculation of the raw materials mixture to manufacture the Portland cement of usual mineral-containing composition has been performed on the basis of the average data of the chemical composition of all raw materials components in accordance with method [1,2]. Since industrial waste characterized by inconstant mass ratio of the components is used as raw materials calculations were done by a computer in order to provide the conformity of chemical composition of the raw materials mixture to the preset mineralogical composition of the produced clinker. Calculated data of seven compositions of the raw materials mixture are given in Table 2.

Chemical composition of the obtained samples of the raw materials mixture was determined by the calculation in accordance with data of Table 1 and Table 2 and was monitored by the X-ray spectrum analysis. Comparative characteristic of the raw materials mixture is shown in Table 3.

The mineralogical composition of the clinker was calculated in accordance with the data of chemical composition of the raw materials mixture. Comparative characteristic of the preset and calculated mineralogical composition of the clinker is given in Table 4.

To determine correspondence of the clinker mineralogical composition produced from the waste to the calculated data the raw materials mixtures of the compositions given in Table 2 were calcined in a tube electric furnace under 1,300 C temperature during 30-40 minutes. After grinding of the obtained clinker up to specific surface of 3,000 cm^2/gram its phase composition and its physical-mechanical characteristics were determined.

Diffiactographies of the obtained cement (fig. 3) show the phases of tricalcium silicate C_3S, dicalcium silicate C_2S, tricalcium silicate C_2S, dicalcium silicate C_2S, tricalcium aluminate C_3A and tetracacium alumo-ferrite C_4AF. Minerals which are not specific for Portland cement of usual mineral-containing composition were not found in the investigated samples. Presence of CaO phases (reflexes 2.39; 1.69; 1.46 A), SiO_2 (reflexes

4.29; 3.37; 2.28 A) and AL_2O_3 (reflexes 5.58; 4.87; 3.195 Å) indicates the low temperature conditions of the calcination of the raw materials mixture caused by characteristics of a laboratory electric furnace.

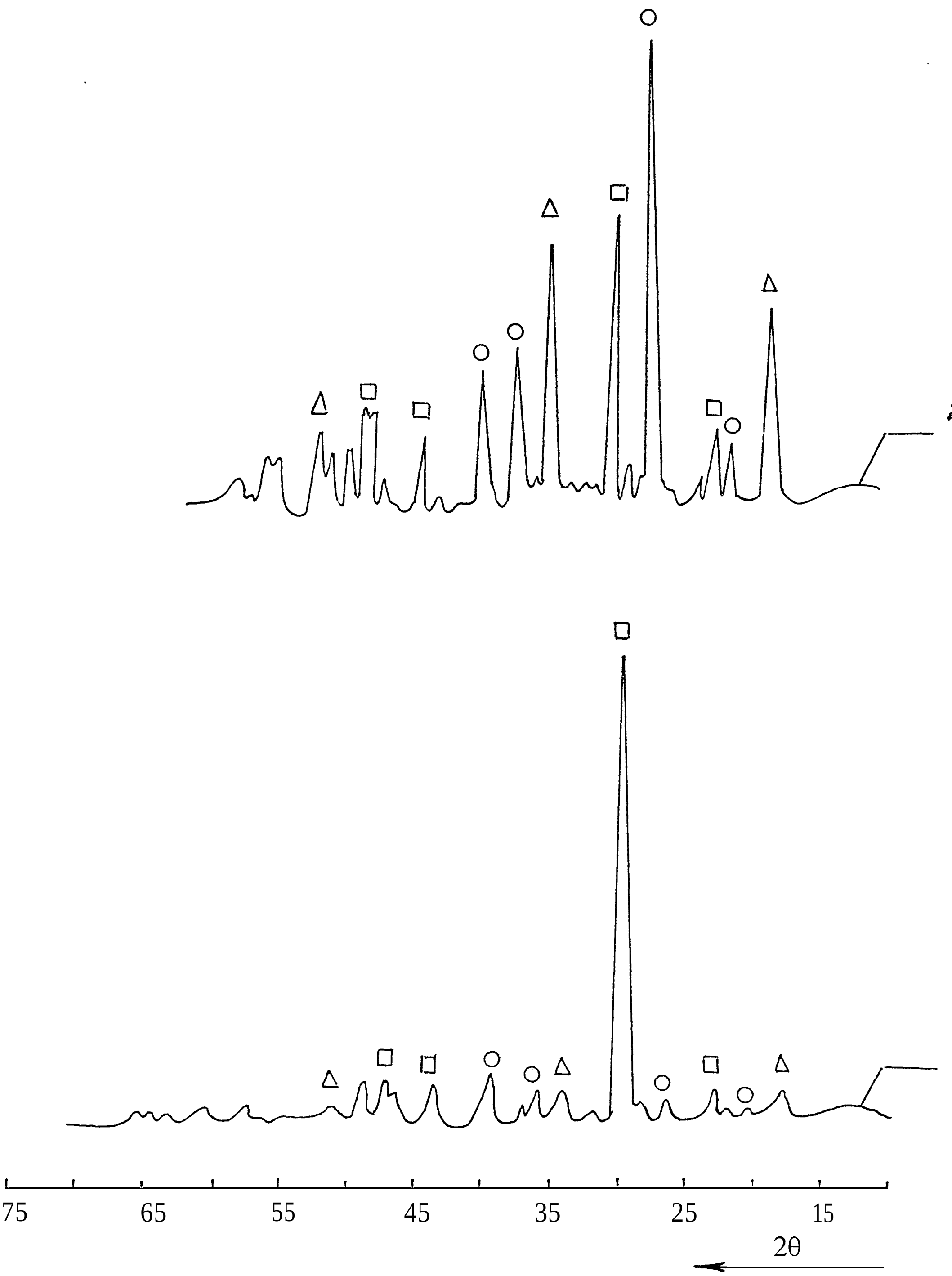

Fig.1 Diffractographies of the tested samples of the self-slaked lime (curve 1) and neutralized lime (curve 2):
□ - $CaCO_3$; A - $Ca(OH)_2$; o - SiO_2

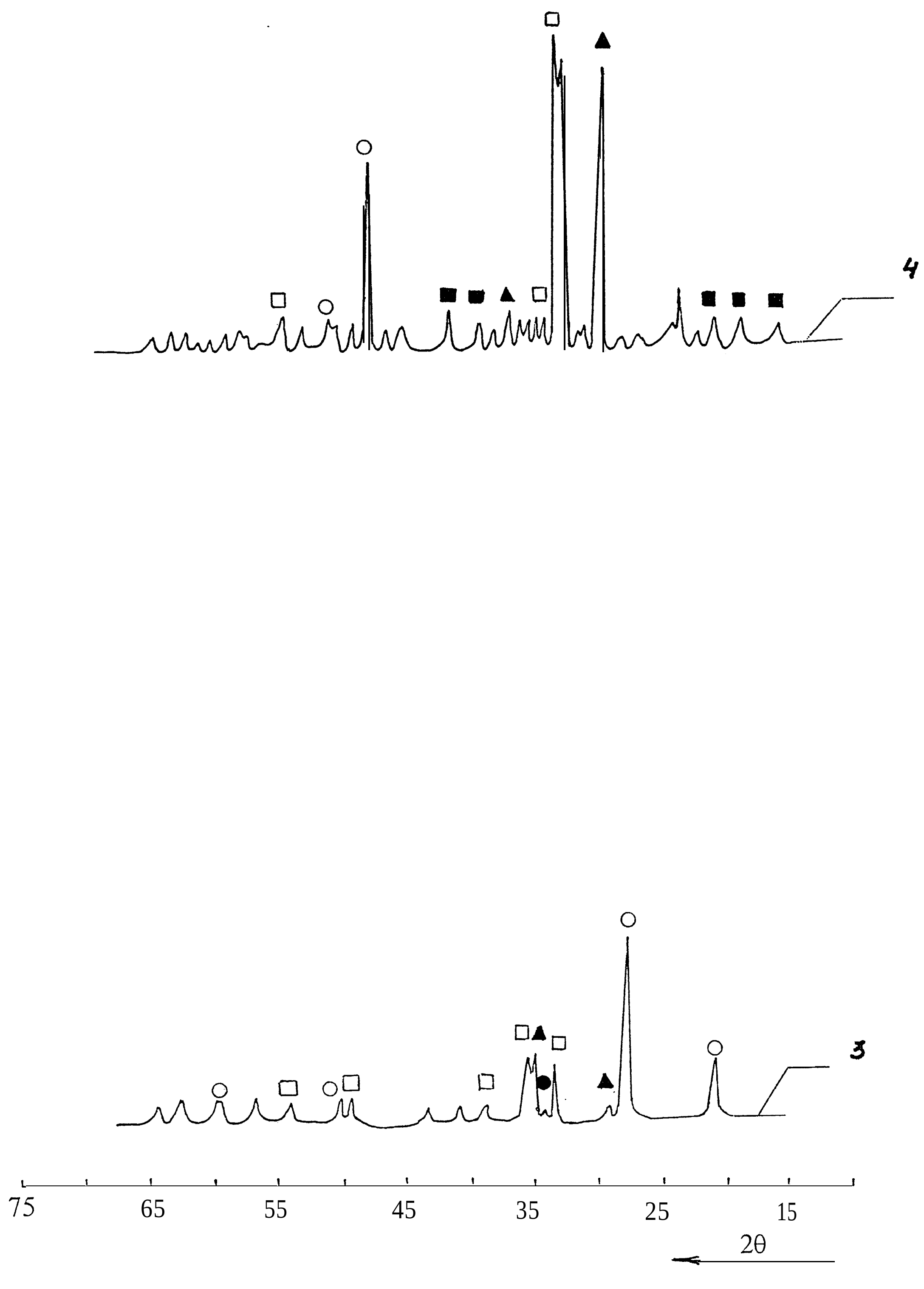

Fig.2 Diffractographies of slime of lime after chemical purification of water (curve 3) and diethylbenzol production slime (curve 4):
□ - Fe_2O_3; ▲ - Fe_3O_4; ○ - SiO_2; ▲ - $CaCO_3$; ● - $Ca(OH)_2$; ■ - Al_2O_3

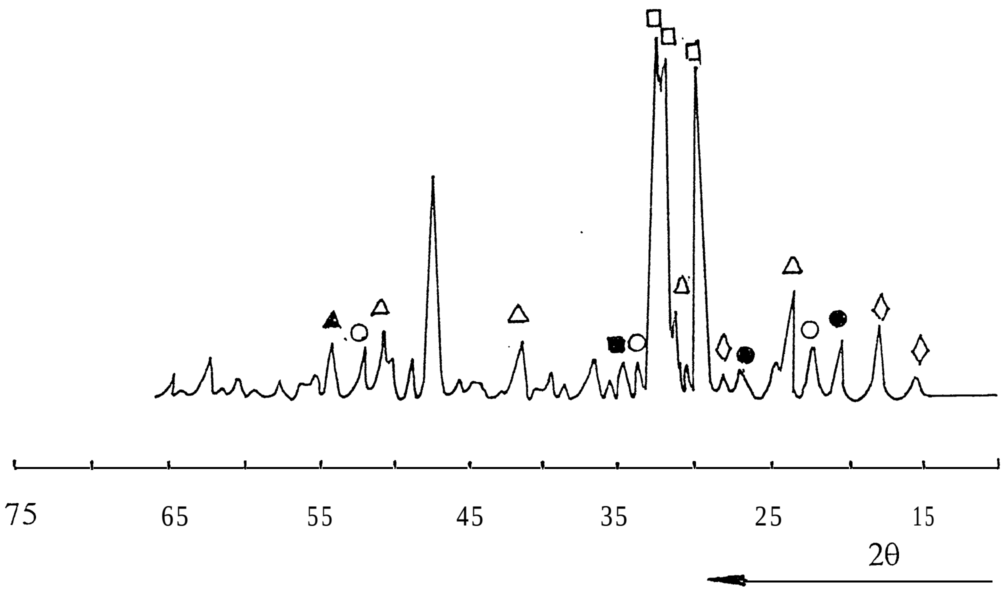

Fig.3 Diffractograhy of Portland cement:
□ - C_3S; Δ - C_2S; ○ - C_3A; ■ - C_4AF; ▲ - CaO; ● - SiO_2; ◊ - Al_2O_3

Table 1. Average chemical composition of initial raw materials

Components	Content, % mass						
	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	losses when calcining	sum
Self-slaked lime	69.7	4.3	0.14	2.0	1.9	21.96	100
Neutralized lime	40.6	47.9		2.4	1.0	8.10	100
Sludge of lime after chemical purification of water	30.3	2.86		18.6		42.24	100
Sludge of diethylbenzol production		15.9	44.85	2.23		37.02	100

Table 2. Composition of raw materials waste

Components	Content, % mass						
	Number of composition						
	1	2	3	4	5	6	7
Self-slaked lime	51.51	57.56	55.86	57.01	57.66	58.12	52.82
Neutralized lime	28.55	29.73	27.76	30.27	28.36	29.84	29.60
Sludge of lime after chemical purification of water	11.07	3.45	6.48	3.45	3.39	3.48	8.02
Sludge of diethylbenzol production	8.90	9.26	9.90	9.27	10.54	8.56	9.56

Table 3. Chemical composition of raw materials waste

Number of composition	Content, % mass							
	CaO		SiO_2		Al_2O_3		Fe_2O_3	
	cal	test	cal	test	cal	test	cal	test
1	56.10	68.0	11.02	13.6	5.70	6.00	2.51	4.0
2	52.00	61.6	16.60	20.7	5.60	6.00	2.60	4.0
3	50.84	64.1	17.62	17.7	4.06	5.00	3.97	5.4
4	53.24	66.4	18.29	19.0	4.23	5.10	2.72	51
5	52.17	71.9	17.46	91	4.52	5.80	3.21	5.6
6	53.07	73.4	18.53	91	4.24	5.30	2.72	5.4
7	52.73	70.5	17.84	13.1	4.83	10.20	2.70	5.4

Table 4. Mineralogical composition of clinker

Number of composition	Content, % mass							
	C_3S		C_2S		C_3A		C_4AF	
	preset	cal	preset	cal	preset	cal	preset	cal
1	50.0	49.86	25.0	25.16	5.0	5.00	15.0	15.00
2	55.0	54.95	22.0	22.08	8.0	7.91	10.0	10.00
3	55.0	54.94	20.0	20.6	8.0	8.00	12.0	11.99
4	52.0	51.85	25.0	25.14	8.0	8.01	10.0	10.00
5	52.0	52.06	23.0	22.91	10.0	9.98	10.0	10.00
6	60.0	59.43	18.0	18.09	7.0	6.48	10.0	10.00
7	45.0	44.30	30.0	30.70	7.0	6.95	12.0	12.97

Results of the physical-mechanical tests given below testify also to advisability of the analyzed waste use for Portland cement production of usual mineral-containing composition which meet demands of the standard.

Normal thickness of the cement paste, %	25
Density, G/cm^3	3.2
Setting time, hrs - minutes:	
the beginning	1-20
the end	7-45

Strength (after steaming)
at the age of 28 days, MPa:

when bending	**4 . 6**
when compressing	**32.6**

4 Conclusions

Conducted investigations have ascertained the chemical and mineralogical composition of the dumped and unused solid waste of chemical production.
It is proved that the main components of waste are carbonate and calcium hydroxide, silicon, ferrite and aluminum oxides.
It is suggested to use the investigated waste as raw materials for production of Portland cement instead of argillaceous and carbonate rocks.

Literature

1 A.V.Volzhenskiy. Mineral adhesives. -M.: Stroyizdat, 1986, p.464.
2 Yu.M.Butt, M.M.Sychev, V.V.Timashev. Chemical technology of adhesives. - M.: Vysshaya shkola, 1980, p. 472.

New Information Service
Environmental Declaration of Building Products

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As a part of “Environmental technology in construction” The Finnish Building Information Institute has developed, in co-operation with industry and Technical Research Centre of Finland, a model of environmental declaration of building material and products. R&D has been carried out in co-operation with the Swedish information dealer Svensk Byggtjänst.

The model of environmental declaration consists of following components

- Product identification
- Service life
- Energy consumption in production and during the service life
- Consumption of raw materials
- Emissions like greenhouse gases, acid rain gases and emissions causing oxidants
- Solid wastes
- Recycling of product and packages
- Healthy at work and assembly and indoor climate.

Model will be tested by creating environmental declarations for some 40 building products (trade names). Declarations and the procedure will be described in the presentation.
Keywords: Ecology, product information, sustainable development.

1 Background

Consumers and decision makers are today conscious about sustainable development and ecology. This is the situation also in construction sector although we know that building has only limited effect on the development of our Globe. So there is a need for new building information about the impacts on biodiversity, harmful emissions and usage of natural resources.

We should remember, that ecology is only one aspect of sustainable development. The others are economical possibilities, social acceptance, political possibilities and cultural traditions. All these aspects should be taken into consideration when making decisions to build a new house or repair an old one.

Therefore its is important, that new, "ecological" information is stored and served as a part of the over all building information. No new organisations are needed, building information centres can take care of information services for sustainable building.

2 R&D activities in the Building Information Institute

The Finnish Building Information Institute has carried out series of state-of-art -studies of sustainable building design in Sweden, Norway, Denmark, Germany, The Netherlands, England and USA. As a result of these studies the Institute has published **Ecological Criteria for Building Design in Finland.** The publication is available in English and free of charge at our homepage www.rts.fi. My presentation is totally based on these criteria.

Ecological criteria are meant to be the basement for our R&D-activities (research and development) concerning both renewal of RT-Building Design Guidelines and creating Environmental Declarations for building products based on Life Cycle Analyses (LCA).

The Institute's R&D is partly financed by TEKES (Technology Development Centre of Finland) through Environmental Technology in Construction programme (1995-99), see www.tekes.fi. A short description of our projects is in www.rts.fi.

3 Recommendations for design guidelines

It is necessary to include environmental information in publications used in project management and design. In client and designer task lists, a checklist is needed of the major questions to be decided in different phases of the project, when the goal is sustainable building. The owner of the building is responsible for defining the level of quality of the project, environmental impacts considered. In publications guiding design and construction quality,(i.e.RYL 90; General Quality Requirements of Construction Works), specification guidelines, design guidelines (RT information sheets), and product information (RT product sheets) more detailed information is called for.

Environmental information about building, and tools for using the information are needed by

- owners with a responsible interest in their own project,
- designers who have to present alternatives to the initiator of the project,
- producers, importers, and exporters, in order to direct their sales according to an environmentally conscious demand,
- construction firms seeing environmental consciousness as a marketing advantage, and
- building branch information services, in order to disseminate information further.

Manufacturers carry the major responsibility of providing information about the environmental impacts of construction products. They have, or should have, information concerning the origin of raw materials of construction products, the impacts caused by their acquisition, their composition, the consumption of energy during production, and the characteristics of emissions caused. The same requirement concerning environmental information applies to prefabricated products, because producers hold the initial information.

The situation is different, when it comes to in-situ building components defined in the specification: no single producer can be expected to provide information about the future *component* (about particular supplies, yes), because the component will only be created on site. Environmental information concerning product components must be calculated based on information about supplies and work processes. The information is to be found in the corresponding design guideline (RT information sheets).

Concisely, information distribution needs to be developed in the following manner:

- product-specific information is provided by the manufacturer in product sheets;
- information concerning prefabricated products is provided by the manufacturer in product sheets;
- information concerning typical components is provided on the basis of calculations in instruction sheets or guidelines.

Information about the environmental impacts of construction is to be concatenated as follows: products and work processes –> typical components –> typical spatial units. A need to update is created by product development, as the chain of production or a working process is improved in order to win a competitive position. Complementary information is needed, when new solutions for building components gain general acceptability, and when new types of spatial units become common.

Compiling environmental information about building in a database that makes comparisons possible means ongoing development activity. Compiling such information provides a challenge for developing products and work processes to become ever more competitive in order to decrease the environmental changes caused by construction, both locally and globally.

4 Product information in building design

4.1 Life cycle analyses and new product information

The result of a life cycle study as well as information concerning the functional qualities of products can be used as a basis of product choice during building design.

An entire building or a mechanical component as well as a construction product can be the subject of a life cycle study.

Because of the abundance and openness to interpretation of information describing the environmental qualities of a product, the conditions of a well-developed utilisation of life cycle study results in the gradual development of design solutions would be significantly improved, if the information were applied in consensus between the producer or component provider and the designer.

When the basic criteria of environmental impacts potentially useful in guiding solutions and choices in the design process are examined, at the moment it is a question of resources and harmful emissions. When it comes to construction products, production processes on the one hand and the service life of products on the other hand have an immediate impact on the creation of environmental stresses.

In building design, the basic intellectual condition for using a result of a life cycle study is that

- the environmental qualities of products are assessed and made known, and
- the distribution and updating of information is organized.

The alternative to be recommended, when it comes to environmental assessment and information distribution concerning products, is that the studies be made by producers. The recommendation is based on the assumption that such a study can then best be grounded in the knowledge about the realised material and energy flows, and, additionally, the study can easily function as a basis for decision-making in process development.

The quality requirements concerning the information about the environmental characteristics of construction products should be set so that the information can be considered useful initial information in a design process.

4.2 Proposal for principles of environmental declaration of a building product

The following is a proposal for the basic principles of assessment of the environmental qualities of construction products. When the basic principles of assessment are agreed upon, it is mainly a question of the limits of the study, arriving at the factors mentioned above, determining the quality of the information.

1. Environmental characteristics are assessed on the basis of a life cycle study, following the methodology presented in the proposal ISOIWD 14041, Life Cycle Inventory Analyses. The following particular principles are observed during the study:
2. The numerical result of environmental impacts is calculated based on the material and energy flows created, starting with the acquisition of raw materials, energy raw materials, and auxiliary materials, and up to the end of product service life. The material and energy flows caused by the unavoidable maintenance operations in order to ascertain the service life will be included. The creation of infrastructure, renovation of production, accidents, and environmental impacts created by workforce will be excluded.
3. Energy resources will be classified as non-renewable and renewable. The energy content of raw materials will be included and can be listed separately. Harmful emissions will be classified to those attributed to air, water, and land. The burning of wood will not be considered to cause carbon dioxide emissions. Occupational health, indoor air, odour, and noise impacts will not be considered in a life cycle study.

4. Land use as a use of resources will not be included in the numerical end result. Environmental impacts caused by the acquisition of raw materials can be estimated qualitatively.

5. The quality of the information is described by its technological, chronological, and geographical coverage, and by an estimate of its representatives. The basic information consists of the annual average values of the material and energy flows of the system under study. In addition to an annual value, information must be acquired about the potential range of fluctuation of the value.

6. If more than one product is created in the process, environmental impacts will be ascribed on the basis of natural causality, or a physical parameter like mass, chosen with reason. Environmental impacts will not be ascribed onto secondary products of little value.

7. The result of a life cycle estimate will be presented in relation to the product service life indicated by the producer. For a life cycle study, a building and a building component must have a proposed service life. In a service life estimate of building components and products included in them, only technical damage will be taken into account. A life cycle study will include an estimate of the material and energy flows necessitated by maintenance.

8. The estimated numerical end result of environmental impacts will not include the material and energy flows during a potential re-use or recycling of the product. In a life cycle study, only the actual practice will be taken into account. If the re-use of the demolition products has been organised, some of the environmental impacts will be allocated to the next round of use. Environmental impacts will not be allocated to a recycled product, if it is of little value compared to the original one. The use of wood products as fuel after their service life will be taken into account in the energy balance.

9. "Savings" in energy consumption occasioned by the exceptional thermal characteristics of a product will not be included in the numerical end result. The impact of the exceptional thermal characteristics of a product can, however, be estimated numerically, and indicated separately.

10. The result will be given as per mass and a suitable functional unit.

11. The best comparable unit in a building is a space. The environmental characteristics of a space will be derived from building components, which consist of certain products. In comparing products, building products consisting of materials and supplies will be discussed as functional units. Equivalent products will be defined as follows:

- function,
- composition, and
- proposed service life.

4.3 Environmental characteristics as part of the attributes of building products

Systematic lists of attributes are available for organising information in the field of building. Internationally significant lists of attributes have been devised by CIB (Conseil International du Batiment) and IS0 (International Organization for Standardization) (CIB Master List 1993, IS0 6241). On the basis of the CIB and IS0 results, a Finnish master list of attributes has been created, with the following areas of information:

- identification
- description
- composition

- agents, requirements, properties, and
- additional information.

Among properties, the attribute of environmental properties is listed. According to the master list, energy expended in manufacturing and the proportion of non-renewable and renewable natural resources used will be indicated in the description of environmental properties, and re-use and recycling characteristics, demolition, or returning to the manufacturer after use will be reported.

In the following, an expanded definition of the attribute of environmental properties will be proposed:

> In the description of environmental properties, the consumption of renewable and non-renewable raw materials for energy, and the production of harmful emissions per functional unit will be indicated, on the basis of a life cycle analysis (raw materials acquisition, manufacturing processes, transportation, construction, use and maintenance, recycling or final destination). A functional unit is a space or construction product with a predicted service life at point of use.

4.4 Service life and the environmental impacts of products

One way of approaching environmentally conscious solutions in building material development and choice is to distribute the environmental damages caused by resource use and harmful emissions over a period of time longer than previously, i.e. to attempt to extend or ascertain the technical service life of products. Attempts toward a service life extension of construction products can be made besides

- product development, also by
- developing quality assurance of products and construction processes, and
- developing use and maintenance directions of materials and products.

In order to take into account the significance of such procedures in environmental impact assessment and product choice based on environmental properties, service life assessment methods must be included in life cycle analyses of products. In order for manufacturers to be able to give service life estimates, and for the estimates to be comparable, uniform methods should be agreed upon for the estimation procedures of products of various types, and for the argumentation expected for indicating the service life estimates of products.

Significant advances have been made in recent years in service life estimating and planning by ISO, CIB, RILEM etc.

In the environmental assessment of construction products, it is important to be able to utilise the existing knowledge of technical damage assessment for the service life assessment of selected functional units.

5 Environmental declaration of building products in Finland and Sweden

Environmental declaration is a part of normal product declaration. It's target group is a planner or designer in a building process or supplier of building products.

The Building Information Institute and VTT from Finland and Svensk Byggtjanst Ab and Instutet for Byggekologi from Sweden have agreed to start co-operation in producing environmental declarations according the following principles:

1. Environmental declarations will be based on the information produced by life cycle analysis or equal studies that fullfill the quality criteria of ISOIWD 14041 and national recommendations such as those produced in Sweden by Byggsektorns Kretsloppsrad.
2. Environmental declarations will be published in Finland and in Sweden so, that Building Information Institute, in co-operation with VTT, will certificate the Swedish declarations to be valid in Finland and Byggtjänst, in co-operation with Institutet för Byggekologi, will certificate the Finnish declarations to be valid in Sweden.
3. Environmental declarations will include the following information both in Sweden and in Finland.

   1. Identification information of the product
      - Trade name
      - EAN-Code
      - Classification
      - Service object
      - Product dimensions
      - Content of the product incl. CAS-numbers
      - Etc
   2. Service Life
      - Planned service life
      - Qualifications and restrictions
   3. Functional unit
      - Functional unit typical to product or product group
      - E.q. 1 sqm of outdoorwall
   4. Energy Consumption
      - Renewable
      - Non renewable
      - Impact on energy consumption of the building during the service life
   5. Raw materials consumption
      - Ammount of secondary and renewable raw materials
      - Ammount of non renewable raw materials
   6. Emissions
      - Greenhouse gases
      - Acid rain gases
      - Emissions causing oxidants
   7. Waste and recycling
      - Waste of product and waste during construction time
      - Recycling and final placement of packages
      - Recycling and repeated use
      - Use of demolition garbage as fuel
   8. Indoor climate
      - In Finland
      - Classification of finnishing materials
      - In Sweden

- Inre Milj ö (Institutet för byggekologi: Förslag till byggvarudeklaration 97-10-06)

4. Environmental Declarations will be valid for 3 years if no product changes occur.

Analysis of the performances of concrete components made with recycled aggregates

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Abstract

The paper presents the first phase of a research programme that investigates the utilization of recycled aggregates coming from crushed concrete rubble in the production of precast blocks. In particular, the paper reports the results of the characterization of the aggregates and of the performance evaluation of concrete specimens in which different percentages of recycled aggregates are contained. The testing of the precast blocks will be carried out during the second phase of the study.
Key words: characterization, concrete performance, recycled aggregates.

1. Objectives and research phases

The aggregates resulting from the processing of concrete rubble in a crushing plant located in Corbetta (Milan, Italy) have been analyzed, and their compliance with the Italian standards about the use of aggregates in medium strength concrete has been verified. In particular, first the characterization of the aggregates has been carried out and then different series of concrete specimens have been prepared following a mix design procedure which optimized the use of these aggregates, with respect to what is known about their performances from international studies. The research was aimed at finding out indications both for the utilization of these aggregates in precast concrete and for the improvement of rubble crushing technologies. In detail, it has mostly focused on the following:

- grading curve of the concrete mixtures: the fine fraction of recycled aggregates, which is believed to be the most problematical, has been replaced with natural sand;
- water/cement ratio of the concrete mixtures, taking into account the water absorption properties of grains;
- mix design.

The analyses have been carried out according to the test procedures and acceptance limits envisaged by the Italian standards on natural aggregates (UNI 8520 series) and to the exposure classes envisaged by prEN 206 on fresh and hardened concrete. These standards are an useful reference also for recycled aggregates, awaiting the European standard approval.

The UNI 8520 series proposes three categories of acceptance limits for aggregates. Each category corresponds to specific final uses, as mentioned in Table 1:

Category **A**	Category B	Category C
use in concrete with $R_{bk} \geq 30$ MPa or exposed to aggressive actions	use in concrete with R_{bk} up to 30 MPa	use in concrete with $R_{bk} \leq$ 15 MPa

Table 1: UNI 8520 acceptance limits

The relationship between requirements for concrete and enviromental conditions is expressed by the exposure classes envisaged by prEN 206 "Concrete - performances, production and conformity", which relate the properties of the aggregates to the final use. The most important property for the aggregates, envisaged by prEN 206, is their density which is regarded as an effective indicator of their global quality.

2. Characterization of recycled aggregates

The analysis of the properties of recycled aggregates is an important step in order to formulate their best use. Therefore, two fractions of aggregates with grading 0/7 mm and 0/16 mm have been characterized. The following paragraphs show the test results.

2.1 Composition and grading curve of the aggregates

The studied aggregates include the following material fractions, expressed by weight: "natural" coarse aggregates (gravel): 75%; tile: 7,5%; old mortar 14%; sand (grading < 0,5 mm): 2%; polluted aggregates: 1%; bitumen: 0,62%; expanded clay: 0,13%; vegetable lightweight lumps: 0,02%. The percentages expressed by volume are similar. Table 2 and Table 3 show the grading curves of the fractions 0/7 mm and 0/16 mm.

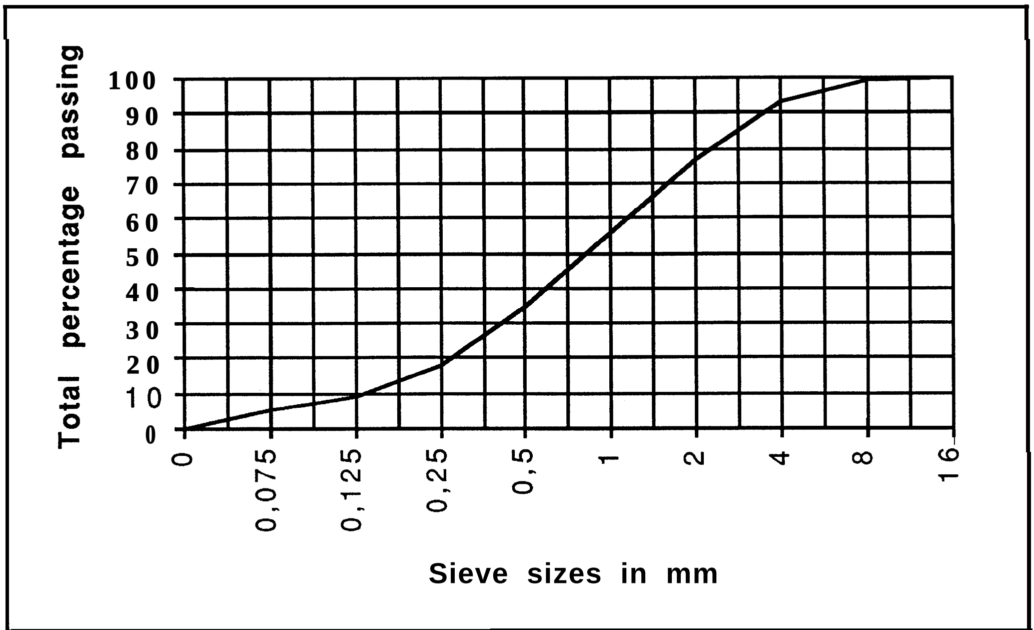

Table 2: Grading curve of aggregates 0/7 mm (UNI 8520-5)

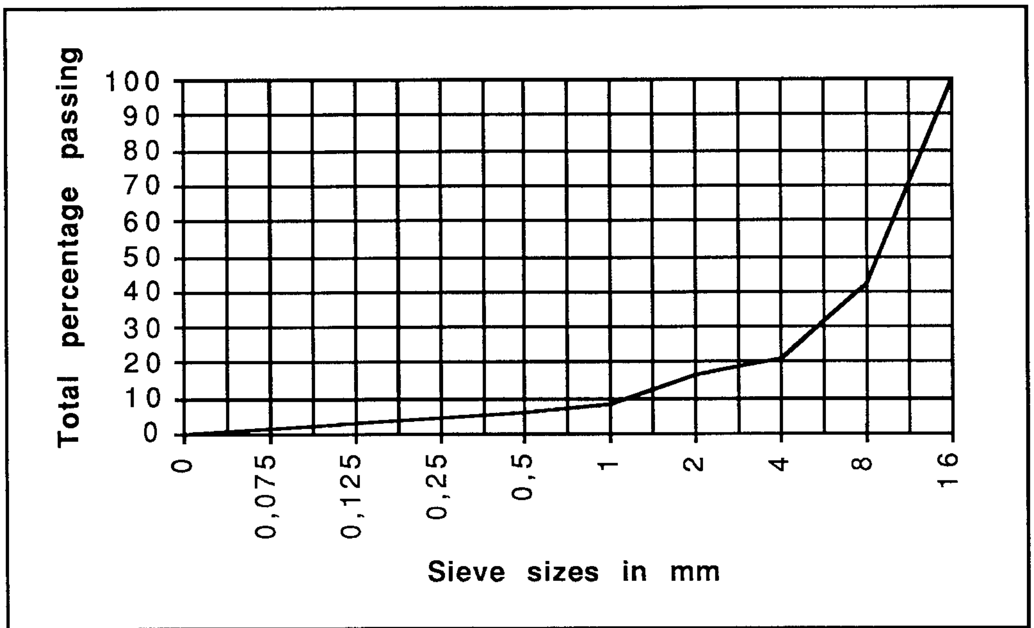

Table 3: Grading curve of aggregates 0/16 mm (UNI 8520-5)

2.2 Fineness Modulus (UNI 8520-5)

The Fineness Modulus (MF) individualizes with a single numerical parameter the particle size distribution as a whole. The analyzed aggregates have the following fineness modulus:

- Fraction 0/7 mm: 4,08
- Fraction 0/16 mm: 6,97

2.3 Determination of soluble sulphates (UNI 8520-11 Method A)

The sulphates contained in the aggregates normally originate from gypsum but only soluble sulphates are reactive and, if present in big amounts, may cause damage to concrete because of their swelling inside the material.
Test results set the fine fraction slightly beyond standard acceptance limits, while coarse fraction falls within those values. Table 4 shows the results.

Average Soluble Sulphates content % (SO3)		Acceptance limits (UNI 8520-2)
Fraction 0/7 mm	0,2439 %	$SO_3 \leq 0,20\%$.
Fraction 0/16 mm	0,1923 %	

Table 4: Soluble sulphates content

2.4 Sand equivalent and methylene blue value of fine aggregates (UNI 8520-15)

Sand equivalent (ES), which expresses the volumetric percentage of clean sand on the whole sedimented aggregate, is used as an indicator for detecting an excessive presence of slime clayey material, which is noxious for concrete. If ES value is under 90, it is advisable to define the methylene blue value (VB) which, unlike ES, distinguishes between slime clayey material and very fine ground stony material useful for concrete.
The ES test has been carried out only for the 0/7 mm fraction because it is envisaged only for fine aggregates; it is however important to specify that the analyzed recycled aggregates cannot actually be considered as fines: in fact, the standard regards as fines

only those aggregates more than 95% of which passes through the 4 mm sieve; on the contrary, only 93,57% of the analyzed fraction (0/7 mm) passes through the same sieve.
Test results set the analyzed aggregates within the acceptance limits (see Table 5).

ES	Acceptance limits (UNI 8520-2)	VB (cm/g)	Acceptance limits (UNI 8520-2)
86,63	Category A: ES ≥ 80	0,32	Category A: VB ≤ 0,6 cm3/g of fine
	Category B: 70 ≤ ES ≤ 80		Category B: VB ≤ 1,0 cm3/g of fine
	Category C: ES = 70		

Table 5: Sand equivalent and methylene blue value of fine aggregates

2.5 Determination of organic impurities content of fine aggregates (Colorimetric determination - UNI 8520-14)

Organic impurities can give rise to different problems such as reduction of cement hydration, worsening of the dimensional instability of concrete when subjected to alternate dry/wet cycles, trapping of excessive air amounts in concrete, which reduce its mechanical properties.
As envisaged by the standard, three single specimens have been analyzed: they have shown a clearer coloring in comparison with a reference solution.
Such results widely fall within the acceptance limits.

2.6 Density and water absorption of fine aggregates (UNI 8520-13) and of coarse aggregates (UNI 8520-16)

The density and water superficial absorption test has been carried out with the pycnometer method for the fine aggregates, while for the aggregates with diameter larger than 4 mm (to be used in concrete) the utilized method was hydrostatic weighing. Table 6 reports the results.

	Fraction 0/4 mm	Fraction 4/7 mm	Fraction 4/16 mm	Acceptance limits (UNI 8520-2)
Mvess (kg/m3)	22143,3 (kg/m3)	2238,2 (kg/m3)	2334,61 (kg/m3)	//
Mvsa (kg/m3)	2394,9 (kg/m3)	2361,28 (kg/m3)	2452,88 (kg/m3)	Category A: MV≥2400(kg/m3) Category B: MV≥2200(kg/mc)
Water absorption %	8,15 %	5,43 %	4,68 %	Category A: ≤ 5% Category B:≤ 10%

Mvess = Real average density with dried particles
Mvsa = Real average density with water saturated dry surface conditions
Table 6: Density and water absorption

Fractions 0/4 mm and 0/7 mm are included in Category B of UNI 8520-2, while fraction 4/16 is included in Category A; it seems that the inclusion of fine grains in Category B

can be ascribed to the larger percentage of cement paste which coats them and gives rise to a density reduction. As a matter of fact, the international standard trend is to limit the possible cement mortar contents in recycled aggregates by defining an acceptance limit of density for them.
The analysis has shown that recycled aggregates have a high water absorption value compared to the set limits for natural ones. The mix design hereafter proposed has considered this chatacteristic.

3. Performance evaluation of concrete

A series of concrete specimens have been prepared using the analyzed recycled aggregates in order to verify the mechanical properties of concrete. In particular, the following mixtures have been compared:

- a mixture prepared with 100% of recycled aggregates;
- a mixture in which the fine fraction has been replaced with natural sand;
- a mixture prepared with 100% of natural aggregates ("witness mark"), which represents a reference mark for the performance evaluation of concrete made with recycled aggregates.

The mix design and the mixture procedures have considered both the international experiences on the matter and the results of the previous characterization phase: the definition of the mix design has in particular consisted in the search of the best possible grading curve and in the study of the water/cement ratio. Moreover, the recycled aggregates have been pre-wet before the preparation of the mixture in order to obtain saturated dry surface conditions. As far as other characteristics of the concrete mixing process are concerned (slump, type of cement, casting time, etc.), they have been kept constant in order to better outline the different performances of concrete made with recycled aggregates. The cement used is type 42,5 R UNI ENV 197 - 1 CEM II.

3.1 All recycled mixture (AR3)

It is the mixture produced with 100% of recycled aggregates; in order to define the best admeasurement of the two available fractions, a numerical method based on Fineness Modulus has been applied. The proportions thus defined have then been adjusted, by approximation, to Fuller optimum curve. In fact, the available granulometry had proved to be too rich in fine fraction (2 mm sieve), which is very critical for recycled aggregates; the proportion of the two fractions has been therefore corrected by reducing the fine fraction percentage.
The mixture which most approaches the Fuller optimum curve is made with 35% of 0/7 mm fraction and 65% of 0/16 mm fraction.

Mixing procedures

The aggregates have been let saturate for 15 minutes in the concrete mixer with 8,25 litres of absorption water and some revolutions have been applied; then the traditional procedure has been carried out. The main characteristics of the mixtures are the following:

- Water/cement ratio: 0,77 • Slump: 4 cm • Casting time: 12 minutes

Table 7 reports the compressive strength values:

AR3 Characteristics	***fresh concrete***	***48 hours***	7 ***days***	28 ***days***	90 ***days***
Average density (kg/m3)	2232,30	2192,49	2148,52	2170,67	2117,33
Average compressive strength (MPa)	//	//	21,95	28,59*	31,48

*Mean Quadratic Deviation among the 28 days Compressive Strength values: 0,746

Table 7: Compressive strength values of AR3

3.2 Recycled mixture with natural fine fraction (RSF2)

In this mixture the recycled sand fraction with a diameter less than 2 mm, which is considered the most critical for this kind of material, has been replaced with natural sand in the proper proportion. In order to compare the results, the grading curve has been calculated so as to be as similar as possible to the one of the previous mixture: the fine fraction replaced with the natural sand represents the 41%.

Mixing procedures

In this mixture, a pre-wetting phase has been carried out only for the recycled fraction (15 minutes with 11,5 litres of absorption water). Main characteristics:

- Water/cement ratio: 0,69
- Slump: 3 cm
- Casting time: 11 minutes

Table 8 reports the compressive strength values:

RSF2 ***Characteristics***	*fresh concrete*	***48 hours***	7 ***days***	28 ***days***	90 ***days***
Average density (kg/m3)	2270,61	2231,31	2217,48	2188,15	2186,67
Average compressive strength (MPa)	//	//	26,50	32,48*	38,10

*Mean Quadratic Deviation among the 28 days Compressive Strength values: 0,472

Table 8: Compressive strength values of RSF2

3.3 All natural mixture (NT2)

The "witness mark" mixture has been prepared with natural aggregates only. A granulometric assortment as similar as possible to the one of the recycled aggregates mixtures has been calculated; this mixture has been taken as a reference mark for the comparison of the different hardened concrete types.

To define the appropriate mix design it was necessary to analyze the grading of the available natural fraction (0/3 mm, 3/7 mm 7/15 mm). The calculation of the fineness modulus has allowed to identify, by approximation, the correct proportions of the different fractions which could give rise to a curve as similar as possile to the optimum theoretical one also used for the recycled mixtures: fraction 0/3 mm: 30%; fraction 3/7 mm: 35%; fraction 7/15mm: 35%.

Mixing procedures

For this natural aggregates mixture no pre-wetting procedure has been carried out. Main characteristics:

- Water/cement ratio: 0,66
- Slump: 4 cm
- Casting time: 10 minutes

Table 9 reports the results of compressive strength values:

NT2 Characteristics	*fresh concrete*	**48 hours**	7 ***days***	28 ***days***	90 ***days***
Average density (kg/m3)	2320,98	229 1,46	2274,07	2256,59	2259,56
Average compressive strength (MPa)	//	//	29,39	37,71*	39,72

*Mean Quadratic Deviation among the 28 days Compressive Strength values: 0,911

Table 9: Compressive strength of NT2

4. Conclusions

The analysis of the test results allows to draw up a few comments.

First of all, the evaluation of the fitness for use in concrete of recycled aggregates has resulted into compressive strength values much higher than the minimum required by law for reinforced concrete structures (D.M. LL.PP. n. 19 -1996), that is to say a characteristic resistance R_{bk} of 15 MPa (the Compressive Strength values found at 28 days are assimilable to R_{bk} owing to the small mean quadratic deviations). Even though the same law does not allow to use recycled aggregates in structural concrete, the present study points out that this is not only an acceptable alternative from a technical point of view, but also a promising application, given the environmental advantages that this recycling technology offers: reduction in the exploitation of non-renewable resources and in the production of Costruction and Demolition (C&D) waste to be disposed of in landfill.

Secondly, the comparison between the performances of the three different mixtures has allowed to confirm the assumptions based on the existing writings on the matter, which outlined the effects of certain parameters (water/cement ratio and concrete density) on the hardened concrete compressive strength. With reference to this, the variation of compressive strength values in connection with the variation of water/cement ratios and concrete density values (Table 10) has been examined.

	R_{bk} 28 ***days*** *(MPa)*	*w/c* ***ratio***	***density*** *(kg/m³)*
100 % Recycled (AR3)	28,59	0,77	2170,67
41% Recycled (RSF2)	32,48	0,69	2188,15
100% Natural (NT2)	37,71	0,66	2256,59

Table 10: Main characteristics of three mixtures

NT2 mixture bears the highest compressive strength value obtainable with the selected cement type and slump (37,71 MPa), whereas AR3 mixture bears the lowest value in the set of three for the three mixtures prepared; ultimately, RSF2 mixture (with 41% of recycled aggregates) lies approximately in the middle between the two extremes.

As far as the different water/cement (w/c) ratios only are taken into account, a correlation between their increments and the correspondent reduction of compressive stregth values in the three mixtures stands out. This correlation, though, is much clearer between AR3 and RSF2 mixtures than between RSF2 and NT2. See the variations (A) in w/c ratios :

- $A_{Rbk(RSF2-AR3)}/A_{RbkTOT}$= 42,6%; $\Delta_{a/c(AR3-RSF2)}/\Delta_{a/cTOT}$= 72,7%
- $A_{Rbk(NT2-RSF2)}/A_{RbkTOT}$= 57,3%; $\Delta_{a/c(RSF2-NT2-)}/\Delta_{a/cTOT}$= 27,3%

In fact, the increment of w/c ratio between RSF2 and AR3 is relevant and is likely to be the cause of the contemporary reduction of R_{bk}: if this is the case, then the possible reason for the reduction of compressive strength appears to be the presence in RSF2 of recycled aggregate fine fraction (grading < 2 mm) with its high water absorption value, already addressed by international studies as the origin of the decrease in compressive strength values of concrete.
However, if the NT2 versus RSF2 characteristics are looked into, a much less relevant difference between the respective WC ratios can be observed, while the decrement (A) in the compressive strength values is still comparable to the one already noticed between AR3 and RSF2. The fact that w/c ratios in RSF2 and NT2 are very alike leads to expect the water absorption properties of recycled aggregates contained in RSF2 (41% of the total aggregates by weight and with a grading >2 mm) to be much more similar to the water absorption properties of the natural ones than in the case of AR3 versus RSF2. Therefore, there would appear to be, in this case, another factor responsible for making the compressive strength decrease: the concrete density (∂), which gives a direct measure of the internal presence of voids. In fact, the available data for density decrement are:

- $\Delta_{Rbk(RSF2-AR3)}/\Delta_{RbkTOT}$= 42,6%; $\Delta_{\partial(RSF2-AR3)}/\Delta_{\partial TOT}$= 20,3%
- $\Delta_{Rbk(NT2-RSF2)}/\Delta_{RbkTOT}$= 57,3%; $\Delta_{\partial(NT2-RSF2)}/\Delta_{\partial TOT}$= 79,6%

As previously assumed, the average density values are much more different between NT2 and RSF2 than between RSF2 and AR3, which induces to believe that what is responsible for the further decrement in compressive strength between NT2 ad RSF2 is actually the larger number of voids inside the concrete, since the decrement cannot be entirely put down to the slightly different w/c ratios between NT2 and RSF2.
All in all, the good compressive strength values found for recycled concrete need to be confirmed in the near future through further research dealing with the problem of quality constancy of recycled aggregates over the time, given the non-homogeneity of C&D waste processed in crushing plants. The next phase of the study will look into the possibility of utilizing recycled aggregates in the production of precast concrete blocks.

5. References

1. CEN/TC 154, (1994) *Recycled Coarse Aggregates* for *Concrete* - Partial First Draft for Concrete
2. Draft prEN 12620, (1996) *Aggregates for concrete including those for use in roads and pavements*
3. Draft prEN 206, (1996) Concrete - *Performance, production and conformity*
4. Gargano, *C. (1996) Architettura a basso impatto ambientale: materiali riciclati, ricerca e sperimentazione,* Degree thesis, Universita Federico II, Napoli.
5. RILEM TC 121 Demolition and Reuse of Concrete and Masonry, (1993) *Draft Specification for Concrete with Recycled Materials (Recycled Aggregates)*
6. Hansen, T.C. (1992) *Recycling of Demolished Concrete and Masonry,* Report of Technical Committee 37-DRC Demolition and Reuse of Concrete.

Life Cycle Impact of Floor Coverings: A Model for the Contribution of the Usage Phase

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Abstract
Compared to other industrial products, building products have a significantly longer service life. When applying LCA methodology to building products, one obvious problem is how to take into account the environmental impacts from the usage phase. In this paper, the usage phase is analysed and a proposal for a model is given based on a division of the usage phase into three parts representing frequent, periodical and upgrading maintenance. The model is applied to floor coverings and some preliminary characteristics and results are presented and discussed.
Keywords
LCA, Service life, Environmental impacts, Floor coverings, Usage phase.

Life Cycle Impact of Floor Covering: A Model for the Contribution of the Usage Phase

1. Introduction

Life cycle assessment (LCA) methodologies have developed rapidly during the recent years. The technique is to a large extent used and developed for environmental assessments of short life products from industrial sectors such as packaging and vehicles. LCAs are frequently used for assessment of materials and components either for the purpose of comparing different alternatives or for proposing improvements. The methodologies have to a large extent been adopted into the building sector and have given much valuable input. But, one obvious distinguishing property of building materials and components is their significantly longer service life compared to other industrial products. Therefore, the usage phase might be of major importance in the building sector from an environmental point of view.

Unfortunately, it can be problematic to take the usage phase into account in a product or component LCA. The problems are connected to the lack of information on this phase (Paulsen & Lundblad 1996). To give an overview of the problem, the life cycle is here divided into three main steps:

1) Raw material extraction and production of a product or a component.
2) Maintenance of a product or a component during the usage phase.
3) Waste treatment or recycling of the product or component.

According to LCA methodology, the analysed object has to be assigned a functional unit and the environmental impacts expected from this unit. This means information and data are needed for the whole life cycle of the object (cradle to grave). Normally, for building products, the information and data range is available to the first part of the life cycle, step 1, extraction of raw materials and production of the object, also called cradle to gate inventory. This stage is therefore normally quite simple to handle.

To collect data on the usage phase (here called step 2), information is needed on for example the application of the object in the building, its expected lifetime, maintenance ‘methods and intervals, auxiliary products and local conditions. Without this type of data/information, it is almost impossible to include the usage phase in an LCA for building products.

To analyse stage 3, waste treatment or recycling, information is needed concerning contents of hazardous materials in the product together with knowledge about techniques and market for recycling and development of techniques for waste treatment. Here scenarios normally are based on the assumption that today’s techniques are used in the future. It does not give the same reliability as in step 1, but possibly a reasonable estimation of the possible environmental impacts.

In summary, the first and the last stage of the life cycle can be regarded as less complicated to analyse while the stage in the middle, the usage phase, is more complicated to analyse since the environmental impacts from this stage are difficult to predict. However, one reason for being concerned about the usage phase for building products is the long-term perspective. It could possibly turn out to be the step with the largest environmental impact.

A number of LCAs have already been carried out on long-life products from the building sector, despite the problems with lack of information concerning the usage phase (Erlandsson et al 1994, Jönsson 1995, Erlandsson 1994). In general, two different methods have been used to circumvent the problems. It has either been assumed that the environmental impact from the usage phase is zero, or a comparative analysis has been carried out with the assumption that the environmental impacts from the usage phase are the same for the analysed products. In this case, they cancel out each other.

A method to take this step into account might enable the choice of more favourable products, auxiliary materials or maintenance methods, and at the same time give feedback to manufacturers. Only considering impacts from the first and third step could lead to sub-optimisations, and thereby failure to reduce the total environmental impacts.

One possible solution to this problem is to divide the LCA into the three different steps (1,2 and 3) mentioned above. For steps one and three, an LCA can be carried out with the most commonly used LCA methods. On the other hand, step two has to be analysed in a less traditional way, due to lack of information. The assumed condition is that the product type is known, but not the exact conditions for the usage phase. However, for some product groups it might be possible to predict the most important parameters causing environmental impacts in the usage phase, even though the extent of these impacts can be hard to estimate for each parameter. The needed information is normally unknown until the application of the product is known. However, if the most probable application and circumstances can be reduced to a limited number of possibilities, maybe different scenarios can then be carried out and the expected quantities and extents estimated for each scenario.

In this paper, an inventory of the usage phase for floor coverings is carried out to illustrate this approach and to examine the extent to which environmental impacts can be predicted in the usage phase.

2 LCA-model for floor coverings in the usage phase

The suggested model refers to a scenario in Sweden where the floor coverings are placed in large buildings and maintained by a contracted cleaner, assuming that an industrial cleaning machine is used. No specific floor covering type is selected.

The emphasis is on the external environment. Human health and indoor environment will not be included.

2.1.Determination of environmental impacts from the usage phase

For this kind of flooring, it can be assumed that the maintenance consists of three maintenance stages (Lidström 1997, Franzén 1997), which are frequent, periodical and upgrading maintenance respectively. The aim of the frequent maintenance is to remove dirt and maintain a healthy and aesthetic indoor environment. The aim of the periodical maintenance is to satisfy the technical function of the floor e.g. an easily cleaned surface. For some types of floor coverings, this can be achieved by periodical polishing. Other types of floors do not need any periodical maintenance at all. The aim of the upgrading is to improve an older floor covering to a level where both the aesthetic and technical functions are satisfactory. The upgrading is similar to the action performed for periodical maintenance, but is likely to be more extensive, e.g. non-periodical polishing or grinding of linoleum, wood or stone flooring. This is done only a few times during the whole usage phase, in some cases never. The suggested model in this paper is an overview model where the type of floor covering is not yet decided. With specified type of floor covering, the importance of environmental impacts from periodical and upgrading maintenance should be easier to estimate.

It is suggested that the environmental impacts for floor coverings during the usage phase are a combination of impacts from maintenance products and the maintenance methods in all three maintenance stages mentioned above. This gives six parameters to determine (see table 1).

Table 1	Maintenance stages		
Source of impacts	Frequent	Periodical	Upgrading
Impacts from products	I_{pf}	I_{pp}	I_{pu}
Maintenance methods	I_{mf}	I_{mp}	I_{mu}
Totally from the stage	I_f	I_p	I_u

The total environmental impact I_{tot} in the usage phase can then be calculated as shown in equation 1a or 1b:

$$I_{tot} = I_{pf} + I_{pp} + I_{pu} + I_{mf} + I_{mp} + I_{mu} \quad (1a)$$

$$I_{tot} = I_f + I_p + I_u \quad (1b)$$

For all the environmental impacts one square metre can be used as the functional unit.

2.2 Determination of environmental impacts from the frequent cleaning

The environmental impacts from the frequent maintenance I_f can be expressed as shown in equation 2:

$$I_f = \int_0^T \left[i_{pf}(t) + i_{mf}(t) \right] dt \quad (2)$$

where $i_{pf}(t)$ and $i_{mf}(t)$ are the time-depending momentary environmental impacts per time unit from frequently used maintenance products and methods.

However, this study concerns floor coverings placed in larger buildings and maintained by a contract cleaner. Therefore, the variation over time for daily cleaning can be considered minimal, at least during one year (Lidström 1997). Assuming that the same products and methods are used during the whole usage phase, the yearly environmental impacts will be constant. This is not quite accurate but one possible way to give an estimate of the total environmental impacts. With this assumption, equation 2 can be simplified to equation 3:

$$I_f = N^* (I_{pfy} + I_{mfy}) \qquad (3)$$

where N is number of years for the maintenance period, I,, and I,, are the yearly environmental impacts from maintenance products and maintenance methods respectively, in the case of frequent cleaning. Assuming that only one cleaning product is used, and that the environmental impacts from the maintenance method are caused by energy use, I, can be calculated from equation 4 and I,, from equation 5:

$$I_{pfy} = E_{pf} * A_{pf1} * n_f \qquad (4)$$

$$I_{mfy} = E_{el} * n_f * A_{fel1} * \eta_1 + E_{ew} * n_f * A_{fw1} * AT * c_w * \eta_2 \qquad (5)$$

where

E_{pf}	Environmental impacts from one litre or kg of the used cleaning agent.
E_{el}	Environmental impacts from one MJ electricity, primary energy.
E_{ew}	Environmental impacts from one MJ energy produced to heat water.
A_{pf1}	Amount of cleaning agent for one cleaning.
A_{fel1}	Amount of electrical energy required for one time of cleaning (MJ).
A_{fw1}	Amount of water required for one cleaning (litre).
n_f	Number of times the floor is cleaned during a year.
η_1	Efficiency for electricity production and machinery.
η_2	Efficiency for energy production to heat water.
AT	Increase in temperature when heating water for cleaning.
c_w	Heat capacity for water (0,0042 MJ/kg*°C).

2.3 Determination of environmental impacts from the periodical cleaning

The environmental impacts from the periodical maintenance I, can be expressed as shown in equation 6 also assuming that the same products and methods are used during the whole usage phase, for each periodical maintenance occasion:

$$I_p = N * (I_{ppy} + I_{mpy}) \qquad (6)$$

where I, and I_{mpy} are the yearly environmental impacts from maintenance products and maintenance methods respectively, in the case of periodical cleaning. Here it has to be assumed that several maintenance products are used. At least one product is needed to prepare the floor surface and another to treat and protect the surface for the future. Furthermore, it is assumed that the environmental impacts from the maintenance method are caused by energy use. Thus, the I,, can be calculated from equation 7 and the I_{mpy} from equation 8:

$$I_{PPY} = n_p * \sum_{k=1}^{k=K} E_{pp,k} * A_{pp1,k} \qquad (7)$$

$$I_{mpy} = E_{el} * n_p * A_{pel1} * \eta_1 + E_{ew} * n_p * A_{pw1} * AT * c_w * \eta_2 \qquad (8)$$

where

$E_{pp,k}$ Environmental impacts from one litre or kg from maintenance product No. k.

K Number of maintenance products used for periodical maintenance.

$A_{pp1,k}$ Amount of maintenance product k for one periodical maintenance.

A_{pell} Amount of electrical energy required for one periodical maintenance .

A_{pw1} Amount of water required for one time of periodical maintenance (litre).

n_p Number of times the floor is periodically maintained during a year, (can be less than 1).

2.4 Determination of environmental impacts from the upgrading

The upgrading maintenance can be expressed in almost the same way as the periodical maintenance assuming that the impacts are the same for each occasion, but here there is a difference in the time perspective. The upgrading can be expected to be done only a few times during the whole usage phase. Therefore, it is not appropriate to express the environmental impacts on a yearly basis. Equation 9 shows the environmental impacts from the upgrading maintenance.

$$I_u = m * (I_{pu1} + I_{mu1}) \qquad (9)$$

I_{pu1} and I_{mu1} are the environmental impacts from maintenance products and maintenance methods respectively, related to one upgrading maintenance. The factor m is the number of times this can be expected to be done during the whole usage phase.

Products like abrasive paper and other grinding materials can be taken into consideration, but are excluded in this study, assuming they cause a negligible environmental impact. Therefore, the I_{pu1} and I_{mu1} can be calculated similarly to equation 7 and 8. This is done in equations 10 and 11:

$$I_{pu1} = \sum_{h=1}^{h=H} E_{pu,h} * A_{pu1,h} \qquad (10)$$

$$I_{mu1} = E_{el} * A_{uel1} * \eta_1 + E_{ew} * A_{uw1} * AT * c_w * \eta_2 \qquad (11)$$

where

$E_{pu,h}$ Environmental impacts from one litre or kg from maintenance product No. h.

H Number of maintenance products used for upgrading maintenance.

$A_{pu1,h}$ Amount of maintenance product No. h for one upgrading maintenance.

A_{uel1} Amount of electrical energy required for one upgrading maintenance.

A_{uw1} Amount of water required for one upgrading maintenance (litre).

3. Predictability of input data

In table 2, the parameters from the suggested model are listed together with a suggestion as to where the information should be collected.

Table 2

Type of parameter	Parameter	Where to collect information
Length of usage phase	**N**	Recommendations and feedback from practice
Amounts of products	A_{pf1}, A_{pp1k}, A_{pu1h}	Contracted cleaner
Amounts of electricity	A_{fel1}, A_{pel1}, A_{uel1}	Contracted cleaner
Amounts of water	A_{fw1}, A_{pw1}, A_{uw1}	Contracedt cleaner
Maintenance intervals	n_f	Recommendations
	n_p	Recommendations
	m	Recommendations
Environmental impacts from maintenance products	E_{pf}	Cleaning-agent producers
	$E_{pp,k}$	Manufacturer
	$E_{pu,h}$	Manufacturer
Environmental impacts from energy production	E_{el}	Swedish average
	E_{ew}	Swedish average
Other factors	η_1, η_2	Swedish average
	AT	Estimation of Swedish average

For some parameters, Swedish averages can be used allowing quite acceptable estimates. This concerns environmental impacts from energy production, efficiency factors for water heating and temperature increase needed for water in the different maintenance steps.

With regards to environmental impacts from the products, it is important to know firstly which products are used, and secondly what environmental impacts they have. Therefore, it is important to have LCAs or LCIs (life cycle inventories) carried out on the most commonly used products. Products with the largest market share could be selected and also some environmental labelled products which could serve as benchmarks.

Other key factors are the amounts of products, electricity and water involved. Here it is possible that larger cleaning companies have standard machinery where it is possible to estimate the electricity use and efficiency, and the amount of water for one square metre of floor (Franzén 1997). The dosage of cleaning agents for the frequent maintenance will probably depend strongly on the type of products used. Amounts of products for the periodical and upgrading maintenance are likely to be more predictable when the type of floor is specified.

Regarding maintenance intervals, the specification of type of floor and premises can be used to facilitate the determination. Here, experience from real-estate owners could be useful together with statistics from the Swedish building stock. Predicting the life time of a floor covering can be very difficult (GBR 1996, Langowski 1997). Actually, it is impossible to give an exact answer about the expected life time, because it depends on a number of independent factors, which together determine the total life time of the floor covering.

4. Discussion

It could prove to be possible to give a reasonable estimate of the environmental impacts in the usage phase for floor coverings in Sweden for special types of premises. However, it strongly depends on the predictability of the maintenance method and intervals. Furthermore, an extensive data base on maintenance products has to be created. As mentioned above, the lifetime of floor coverings is difficult to predict and needs further research. Still, a recommendation can be used in a scenario.

The suggested model introduced in this paper has to be tested in a number of case studies to reveal which parameters are most important. To carry out an LCA normally causes problems in deciding on limitations. The question is what to include and what to exclude in an analysis, as it is impossible to take everything into account. This suggested model may have to be extended or reduced depending on which parameters prove most important.

As a final point, it is important to remember that a product LCA is normally performed in the production stage with good knowledge of this step. In contrast, an inventory on the usage phase and waste/recycling stage contains many uncertainties about long lived products. Therefore it seems reasonable to divide the presentation of the LCA into three parts, production, usage phase and waste treatment/recycling, in a transparent way.

References

1. Albrecht, G. Langowski (1997) Life Cycle Assessment Study on Resilient Floor Coverings. *The International Journal of Life Cycle Assessment,* Vol. 2, No 2. pp. 73-80.
2. Information from GBR (Swedish National Flooring Trades Association), Stockholm (1996).
3. Erlandsson, Martin et al.(1994,) A comparison Between Three Different External Walls and Possible Improvements, Swedish Waste Research Council, AFR Report no. 35.
4. Paulsen, J. and Lundblad, D. (1996) Ramverk för miljöbedömning av Byggnadsproduker, *Framework for Evaluation of Environmental Impacts from Building Products* (in Swedish), Trita-Byma 1996:5, Division of Building Materials, Royal Institute of Technology, Stockholm, Sweden.
5. Jönsson, A, (1995) Life cycle assessment of Flooring Materials- A case study and methodological considerations. Licentiate thesis, Technical Environmental Planning, Report 1995:3, Chalmers University of Technology, Göteborg, Sweden.
6. Erlandsson. M.. (1994) A Comparative Life Cycle assessment of Roof Coverings, Swedish Waste Research Council, AFR Report no. 35.
7. Lidström, R. (199 *7) (ISS, Swedish cleaning company)* Personal communication.
8. Franzén, T. (1997) *(Partena, Swedish cleaning company)* Personal communication

Autoclaved aerated concrete for construction in hot regions

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Abstract

The common construction system used in Kuwait is a frame structure consisting of reinforced heavy concrete beams and columns with reinforced floors and roof slabs. Walls are constructed by filling the skeleton with masonry blocks. This type of construction is the dominating system used in the Arabian Gulf Countries and is even used in one and two story residential buildings.

Autoclaved aerated concrete (AAC) was introduced in the mid 1980's as an alternative material that can provide both the structural and heat resistance characteristics required. AAC is produced as masonry units to be constructed in RC skeleton construction, in addition to reinforced AAC panels which are constructed as a homogeneous AAC precast system.

This paper reviews the performance of buildings constructed using AAC. The structural and thermophysical properties are presented. Patterns of energy consumption of a typical building were developed using a computer building simulation program and energy savings calculated. Finally the findings are reflected on the national scale as environmental aspects of the production process, building performance and power supply requirements.

Keywords: Autoclaved aerated concrete, building performance, energy consumption, hot regions.

1 Introduction

Concrete frame structure is the common construction system in Kuwait. Such a system consists of a skeleton of reinforced concrete beams and columns with reinforced concrete floor and roof slabs. Walls are constructed by filling the skeleton with masonry blocks. This type of construction is even used in one and two story residential buildings. Load bearing wall construction is rarely used. The most commonly used masonry blocks are made of solid heavy concrete with a low compressive strength. With such practices, the unit weight of wall construction could reach 380 kg/m^2 while the unit weight of roofs reaches up to 440 kg/m^2.

Kuwait's summer lasts from April to October; it is hot, with maximum temperature reaching 50 °C or more in shade; and it is dry, although relative humidity can reach 60% in late summer and 90% in autumn and winter. Solar radiation is high; in late summer it may reach 1,100 W/m^2, and there are more than 230 days of clear sky in a year. Winter temperatures arc in the range of 10-20 °C. Rainfall, which occurs between October and May, is sparse; it may range from as little as 50 mm to more than 300 mm. Average wind speed is 3 m/s. The prevailing wind is northwesterly and is dry, since it passes over a large region of desert; the secondary wind is southeasterly and moist, since it comes in from the Arabian Gulf.

Electrical energy consumption is governed by the need for space cooling, to the extent that air-conditioning peak power consumption in Kuwait during the summer reaches 70% of the total generated . The excessive demand for air-conditioning is attributed to the extreme ambient air temperature during the summer. Though a large proportion of the increase in demand has been caused by the steady increase in per capita consumption, an important factor contributing to the increasing consumption rate is the government's subsidy to consumers, reflected by the low price of the electric unit. This is as low as 2 fils/kWh, representing 5% of the actual present cost. Another factor is the erroneous assumption that, due to the wide availability of low-cost fuel in oil-rich countries, like Kuwait, power generating costs are trivial. In fact, the production, transmission and distribution costs of electric power place a heavy burden on the state budget, in light of the world energy crisis and such factors as the import of equipment and technical skills.

2 Energy conservation measures

In response to the rapid increase in electricity demand, conservation measures had to be introduced and enforced to curtail the energy requirements in buildings. The Kuwaiti Ministry of Electricity and Water (MEW) code of practice for energy conservation in buildings [1] sets several requirements to limit the peak loads for space cooling. The peak electrical load for residential buildings is set at a maximum of 65 W/m^2. To meet such requirements, the code presents target minimum standard for energy conservation measures. Table 1 specifies maximum thermal transmission allowed for walls and roofs of heavy construction. To comply with the Kuwaiti energy code, exterior heavy walls should include a layer of 5 cm thermal insulation material while a 7 cm thermal insulation material should be embedded within heavy roof sections.

Table 1. Maximum Thermal Transmission (U-Value) Allowed for Walls and Roofs of Heavy Construction.

	Maximum Overall U-Value	
	BTU/h ft^2 °F	W/m^2K
Wall	0.10	0.57
Roof	0.07	0.40

3 Autoclaved aerated concrete

The enforcement of strict limits on the thermal resistance for exterior walls gave way to the introduction of autoclaved aerated concrete blocks as an efficient material that can provide the necessary thermal insulation properties without the use of specific thermal materials. Autoclaved aerated concrete was developed at the end of the 1920's in Sweden [2]. Cement and lime, together with siliceous fine materials such as sand, slag or fly-ash and water, are used as raw materials. A small amount of aluminum powder is added. A chemical reaction between the aluminum powder and the lime increases the volume by forming air-filled cells. The product is autoclaved for 10 hours at 10 atm at 180 °C. The autoclaving initiates a reaction between the calcium and silica to form calcium hydrosilicates.

Autoclaved aerated concrete has a low bulk density and a particularly favorable ratio between material strength and bulk density. The lower bulk density consequently causes a lower consumption of raw materials which is shown by the way of comparison to other building materials in figure 1 [3]. Furthermore, autoclaved aerated concrete posses remarkable possibilities for waste processing and recycling. Since the material can be easily cut and sawed with simple tools making it possible to reduce the waste in the site to a minimum. A main feature in that is the recycling processes used in typical AAC plants.

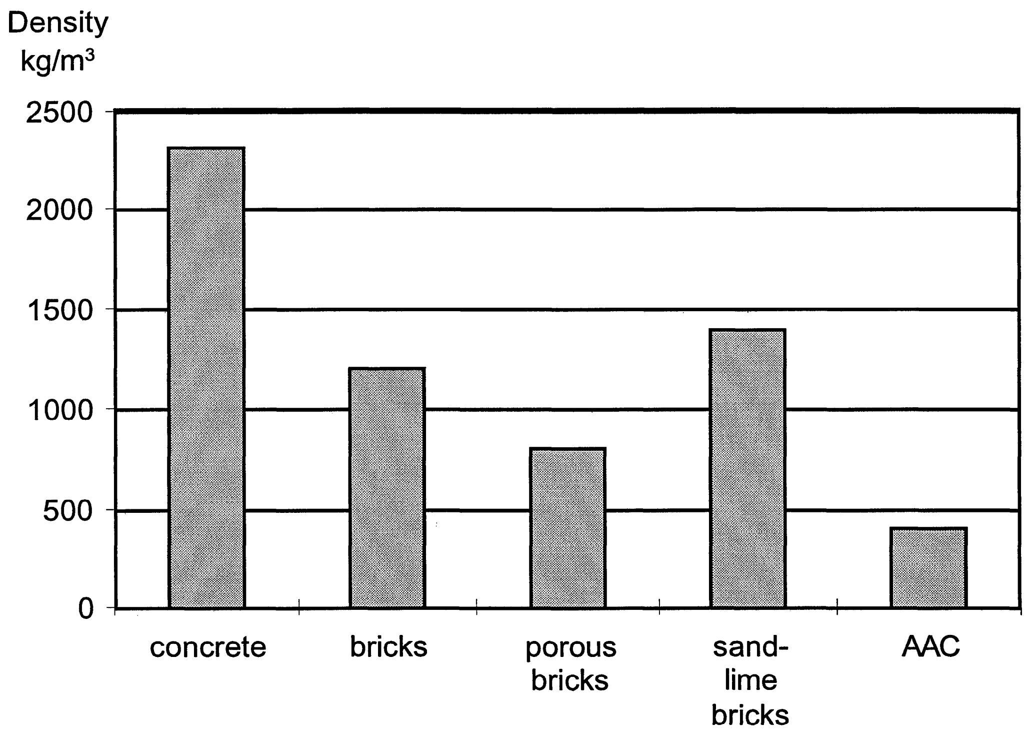

Fig. 1 Consumption of raw materials in the production of building materials [3].

Autoclaved aerated concrete, being a light weight material, provides a useful thermal inertia because it possesses an advantageous combination of mass, thermal conductivity and specific heat properties. This means that autoclaved aerated concrete can reduce the extremes of internal temperature compared with buildings made of lighter structures (which have minimal thermal capacity) or heavier structures (providing less thermal insulation). During the warm season, the thermal inertia of an autoclaved aerated concrete roof of normal thickness works in such a way that inside the building the rise of temperature due to solar radiation is delayed by as much as 6-12 hr, counted from the time of the day when the solar radiation is at its maximum. After this time the effect of radiation decreases considerably. The roof then emits its accumulated heat during the cooler part of the day. Consequently, the capacity of the power plant required for heating or cooling (and the energy required for their operation) can be reduced. Figure 2 presents a typical dynamic heat flow in which there is a time variation of the exterior surface temperature, but the interior temperature is kept constant by heating or air-conditioning [4].

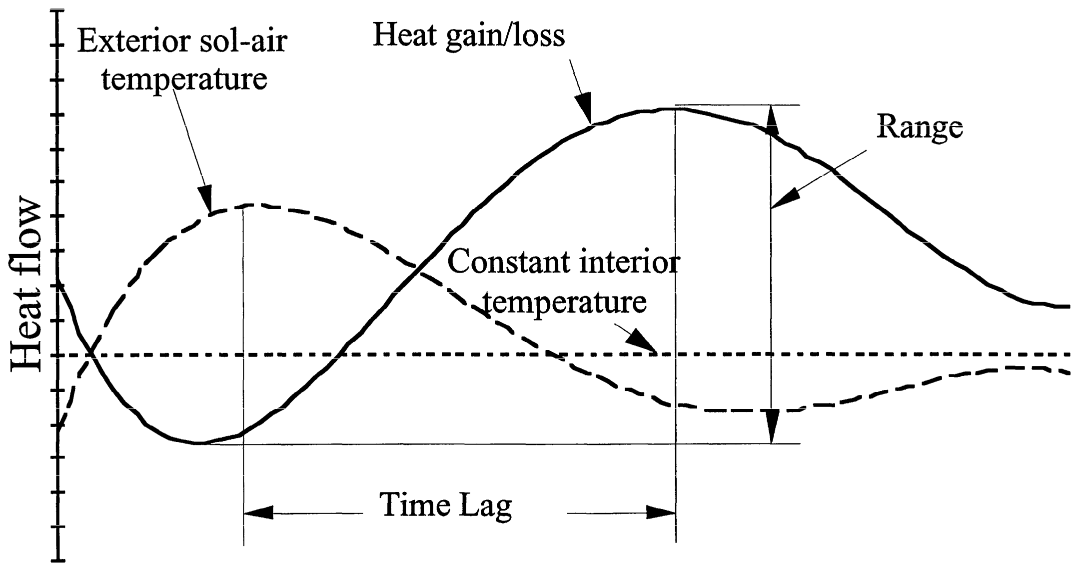

Fig. 2 Dynamic heat flow [4].

4 Use of autoclaved aerated concrete in Kuwait

Autoclaved aerated concrete blocks are produced in Kuwait in densities ranging from 450 to 600 kg/m^3. The most common size is 60 x 20 x 20 cm. A special 2-mm thick epoxy glue mortar is used to bond the blocks. With its superior thermal insulation properties, a 20 cm thick autoclaved aerated concrete block wall finished with sand cement rendering and sand lime brick can satisfy the Kuwaiti energy code without the addition of a thermal insulation material.

Precast autoclaved aerated concrete panels are also produced for use in roof wall construction. Typical panel size is 25 x 60 x 200 cm with densities reaching up to 900 kg/m^3. A building constructed using autoclaved aerated concrete panels precast system in the building envelope (roof and walls construction) will maintain the advantages of this type of construction to its full extent when compared with the mixed system currently used in Kuwait where autoclaved aerated concrete blockwork is integrated with a heavy reinforced concrete frame structure.

5 Energy consumption patterns

To analyze the effect of energy consumption, a typical Kuwaiti house was considered. The technique employed to predict the thermal performance of the building used computer based building simulation. Figure 3 shows a typical hourly power consumption for the building constructed using conventional heavy weight wall and roof systems for both insulated and uninsulated cases. On the national scale, power consumption have been increasing steadily as shown in figure 4. It should be noted that the drop in 1991 was due to the interruptions induced by the Iraqi invasion during 1990/91.

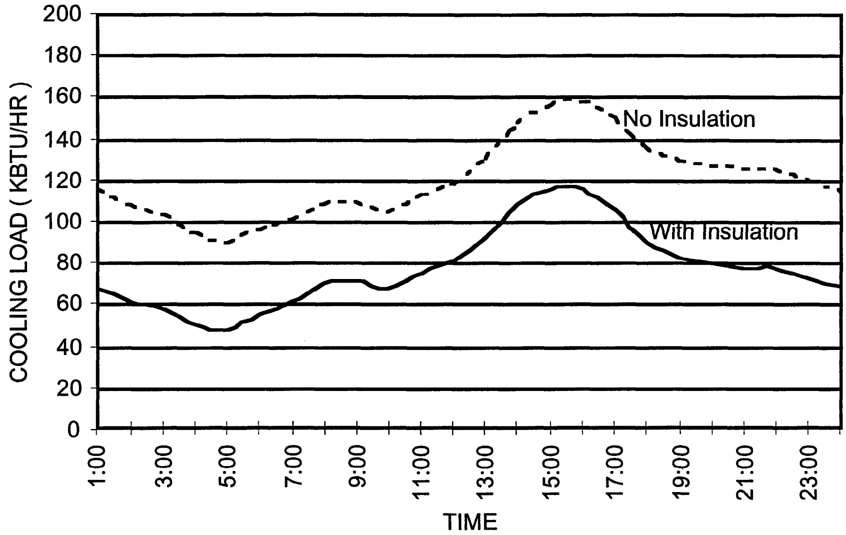

Fig. 3 Typical hourly power consumption for a Kuwaiti house.

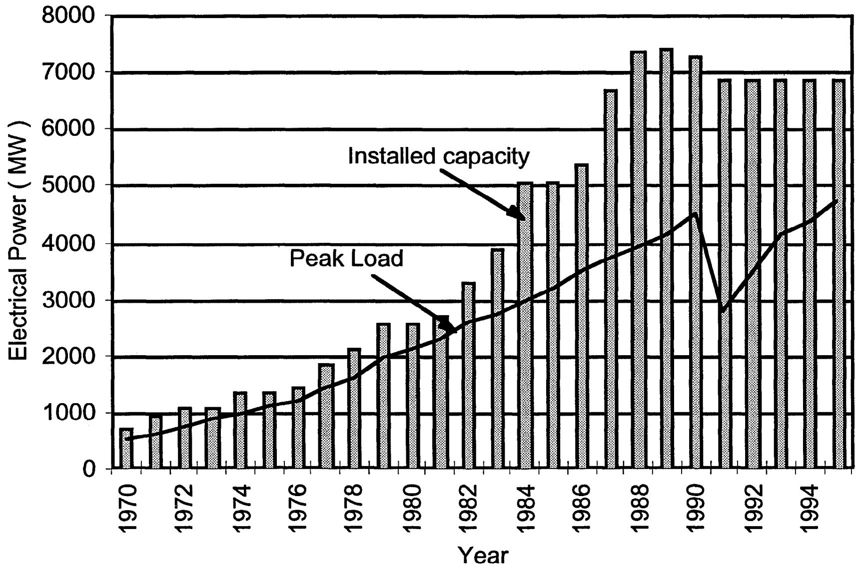

Fig. 4 Peak power consumption compared to installed capacity in Kuwait [4].

As discussed earlier, buildings constructed using autoclaved aerated concrete are expected to posses different hourly power consumption pattern in which the peak load is expected to shift compared to the traditional heavy weight structures. As autoclaved aerated concrete is considered lighter in mass, it is predicted that the peak load will occur with a less time lag compared to heavy structures. Hence if the overall peak load for the residential sector, which represents 85% of the total number of power consumers in Kuwait [5], occurs on 4:00 pm, the amplitude of such peak load can be reduced by shifting to other construction systems that can maintain a different peak time, in this case autoclaved aerated concrete.

Assuming a target of 30% of residential buildings constructed using autoclaved aerated concrete, expected to maintain a time lag that is 2 hours shifted from the 4:00 pm current peak time, will reflect on a peak load shaving of around 260 MW on the national scale. Further demonstration analysis and studies are required to determine the exact reduction in the national peak load as conservatively expressed earlier. It should be noted that achieving such percentage of residential buildings that utilize autoclaved aerated concrete construction is not a difficult goal. A direct sector that can be targeted is the governmental housing program that is expected to deliver around 1000 housing unit annually.

6 Discussion and recommendations

Autoclaved aerated concrete is a building material which can be produced with low consumption of raw materials some of which are recycled waste. It offers remarkable heat insulation characteristics while maintaining strength requirements.

The light weight and thermal inertia properties of the material provides a useful energy consumption pattern that, when integrated with other buildings of different mass, can contribute effectively in peak load reduction on power plants.

A national plan need to be developed for the optimum distribution of buildings as heavy, medium and light weight construction. The optimization will contribute further into reducing the electric peak load consumption. To encourage such shift in the construction industry, incentives need to be developed. Such incentive may be lower prices of the electric unit or defining a lower thermal resistance requirements for light weight walls and roofs. Some authorities have recognized the thermal inertia contribution, such as the California Energy Commission which defines lower R-values [3].

References

1. Ministry of Electricity and Water (1983) Code of Practice for Energy Conservation in Kuwaiti Buildings, Report R-6, Kuwait.
2. Dubral, W. (1992) On production and application of AAC worldwide. Autoclaved Aerated Concrete: Properties, Testing and Design, edited by F. W. Wittman, E&FN Spon, London.
3. Hums, D. (1992) Ecological aspects for the production and use of autoclaved aerated concrete. Autoclaved Aerated Concrete: Properties, Testing and Design, edited by F. W. Wittman, E&FN Spon, London.
4. RILEM Recommended Practice (1993) Autoclaved Aerated Concrete: Properties, Testing and Design, E&FN Spon, London.
5. Ministry of Electricity and Water (1996) Statistical Year Book, Kuwait.

Assessment of the environmental compatibility of concrete admixtures

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ABSTRACT

Concrete and mortar adrnixtures are substances added to concrete or mortar with the aim of influencing their fresh and hardened properties by their physical or chemical action For example, in the case of fresh concrete the flow, the cohesiveness and the setting behaviour are controlled but also the hardened concrete properties such as strength, impermeability, shrinkage, or frost thaw resistance can be positively influenced by the use of a concrete admixture.

Because of their low dosage concrete admixtures play a subordinate part in the multicomponent system concrete. Nevertheless it is our task to evaluate the effect of these chemical substances on the environment before and druing construction but also in the hardened state

In this article we focus on the toxicological and physico chemical properties of the mostely used products in Europe (water reducers and high range water reducers) and their leaching behaviour in recycled concrete.

Keywords: concrete admixtures, environment, leaching, superplasticizers, concrete demolition material

1. Introduction

Concrete admixtures are used specifically to improve workability and the end quality of the concrete to be obtained. With regulation use of concrete admixtures the pollution of the environment to be expected is very slight so that the products can be rated as environmentally compatible.

2. What are concrete admixtures and why are they needed?

Modern concrete contains in addition to cement, gravel, sand, additive and air normally also one or more concrete admixtures. In this way, depending on the nature of the admixture, it is possible to influence specifically concrete properties such as strength, flow behaviour, resistance to frost and deicing salts, sulphate resistance, setting characteristics, pumpability and others. According to prEN 934-2 (Final Draft 1994) a distinction is made between the following categories of concrete admixture (Table 1): The action of superplasticizers is based on long familiar principles. Abram found at the beginning of this century that for a given set of materials and conditions the compressive strength of concrete depends on the proportion of cement in the cement paste. However, as the cement paste consists of cement and water, it becomes clear that the so-called water/cement (w/c) ratio is to be kept low in order to achieve good strength values and durability, for as is well known only a part (approx. 25%) of the water can react with the cement, the excess water evaporating leaving behind pores. The w/c ratio thus has a dominating influence on the properties of the green and the hardened concrete. Using plasticizers or rather superplasticizers (SP) makes it easy to achieve this objective. Air-entraining agents, for example, are indispensible for making concrete resistant to frost and deicing salts. Air voids of a certain size and distribution are deliberately created to act as expansion spaces capable of absorbing the pressure of the freezing water.

	German abbreviation
Concrete plasticizers	(BV)
Superplasticizers (SP)	(HBV)
Air-entraining agents	(LP)
Accelerators	(BE)
Retarders	(VZ)
Integral waterproofers	(DM)
Emulsifiers	(ST)
Corrosion inhibitors	(KI)
Antifreeze agents	(FS)

Table 1: Classification of concrete admixtures

Ecological demands on concrete and also the continuous adaptation and development of construction and working techniques represent a constant challenge to researchers and developers of concrete admixtures. An "ecological concrete" is a concrete which according to ecological criteria has an optimized composition of the individual components (sand/gravel, cement, water, concrete admixture, additives), A crucial criterion in this is the durability of the concrete exposed to the environment. The latter is positively influenced by the proper use of modern concrete admixtures. In total according to FSHBZ statistics approx 14,000 t of concrete admixtures were sold in Switzerland in 1994, whereby the SPs with approx. 75% make up the largest part. Today approximately one third of concrete placed has been modified with a concrete admixture.

Environmental pollution from the use of concrete admixtures has been critically questioned by various quarters. This publication summarizes the state of knowledge regarding environmental pollution caused by the use of concrete admixtures and the effects on man and environment to be expected.

3. Choice of concrete admixtures used for the study

From the different concrete admixtures described above it was superplasticizers (melamine sulphonate polymers and naphthalene sulphonate polymers) that were chosen because of their wide range of uses., the total quantity used in construction and the material properties.

4. Are concrete admixtures environmental1 incompatible?

The effects of chemical products on man and the environment are assessed in accordance with the relevant chemicals legislation [1, 2, 3]. All emissions to be expected in the course of the life cycle of a product are covered and assessed with regard to possible effects.

The following procedure has proved itself in practice:
I. Data collection and evaluation
II, Listing of the life cycle
III. Assessment of environmental compatibility
IV. Measures for improving environmental compatibility

I. Data collection and evaluation
Data from safety data sheets, product tests and scientific studies were used as the database, Various data are product-specific so that special test methods were used. In part the investigations were conducted in cooperation with relevant institutes (e.g. EAWAG[1], EMPA[2]). A selection of relevant data for the currently most important superplasticizers is summarized in Table 2.

[1] Swiss Federal Institute for water, Waste water and Water Protection (EAWAG Diibendorf, Switzerland)
[2] Swiss Federal Materials Testing Institute (EMPA Diibendorf, Switzerland)

Parameter	Naphthalene sulphonate polymer (NSP)	Melamine sulphonate polymer (MSP)
Water solubility	>100 g/l	>100 g/l
Octanaüwater distribution Cow (log)	<<-1*	6-4
Toxicity for mammals LD50 rodent (mg/kg)	3400->4000	>4000
Aquatic toxicity EC50 fish (mgA)	100-2000	560-3200
Aquatic toxicity EC50 daphnia (mgA)	>220	>100
Mutagenicity in Ames test	negative	negative
Biodegradability OECD 302B (%)	43	15-51
Poison category (CH)	free	free
Water hazard class (D)	~ 1	1

* = calculated

Table 2: Selection of relevant data for superplasticizers

All substances are readily soluble in water, have very low octanol/water distribution coefficients (i.e. they do not concentrate in the fatty tissue of organisms) and are not volatile. They are classified in Switzerland as non-toxic and have an acute toxic effect on water organisms only at very high concentrations. They are not easily biodegradable.

II. Listing of the life cycle

The following stages in the life cycle of concrete admixtures can lead to pollution of the environment:

- Production
- Transport
- Storage/handling
- Use of the concrete admixtures
- Service life of the building
- Recycling of concrete from demolition
- Disposal of building waste and residues.

Figure 1 shows the simplified life cycle of concrete admixtures taking the example of the use of ready-mixed concrete.

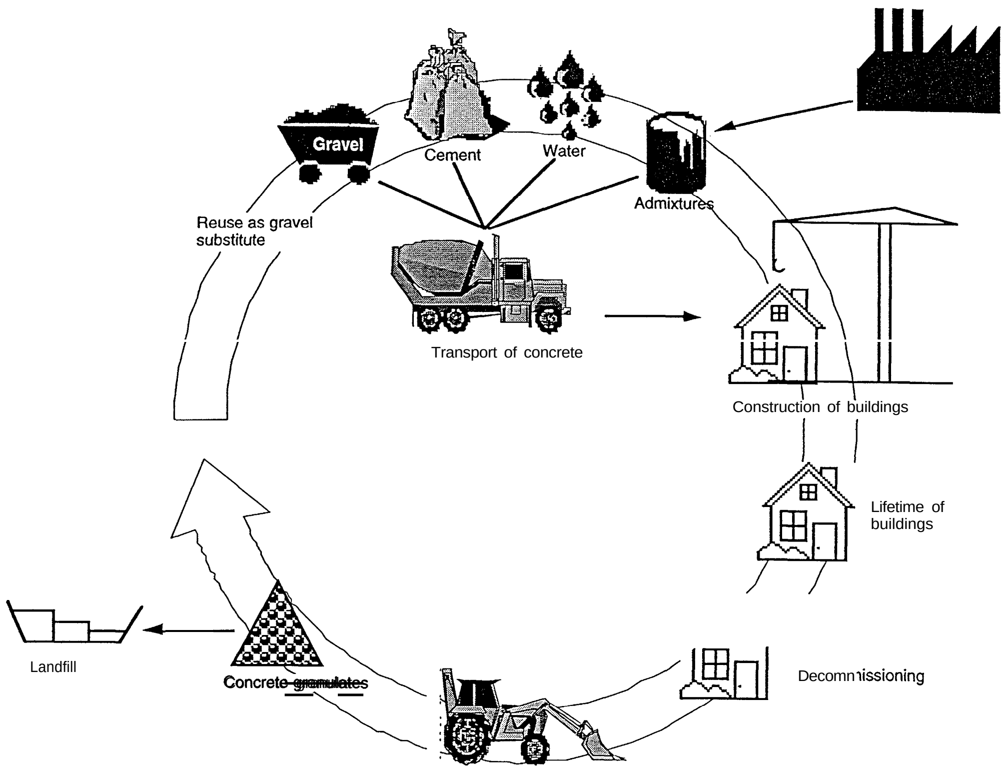

Fig. 1: Simplified life-cycle of concrete admixture

III. Assessment of environmental compatibility

The burden on man and environment was assessed using the emissions found or estimated for each stage of the life cycle. The toxicological and ecotoxicological characteristics of the concrete admixtures served as a basis for the assessment.

4.1 Emission and mass flows

Pollution from SPs was determined experimentally or estimated for each stage of the life cycle of the products It was found that environmental pollution can occur above all when using SPs and when storing concrete granulate containing SPs and when using this granulate in road construction.

4.1.1 Production

Thanks to specific treatment of waste water with recovery of the substances contained in the waste water only very small quantities of SPs get into public purification plants.

4.1.2 Use

It can be assumed that when using SPs in producing precast concrete units no relevant emissions occur.

The use of SPs for preparing in-situ concrete is in swift decline. With proper handling the environmental pollution (e.g. washing of implements) is expected to be very slight.

When used for ready-mixed concrete the main focus is on waste disposal from the rinsing of ready-mix trucks. These emissions are strongly on the decline as on the one hand rinsing water is being increasingly used for preparing concrete and on the other retarders can be added to the concrete remaining in the trucks which delay hardening.

4.1.3 Emissions from existing prefab units

EMPA studies on concrete test specimens have shown that SPs do not cause any appreciable emissions of volatile organic compounds [5].

4.1.4 Emissions from concrete demolition material

Leaching tests with broken material (4-8 mm) from defined concrete test specimens have shown that it is not the originally used SPs that are leached but their decomposition products.

These are readily biodegradable which is favourable for environmental behaviour. Under the strict conditions of testing a total of some 20-30% of the SPs used were leached. As estimates taking one product showed, more than half of the leached material is present in the form of decomposition products.

A comparison of the leachability of defined test specimens containing SPs with concrete granulate from recyclers has shown that only part of the leachable substances come from the use of SPs (Fig. 2). A large part must come from products used in construction (coatings, adhesives, mastic joint sealers, etc.), from foreign materials (wood, gypsum, asphalt, etc.) and the cement itself.

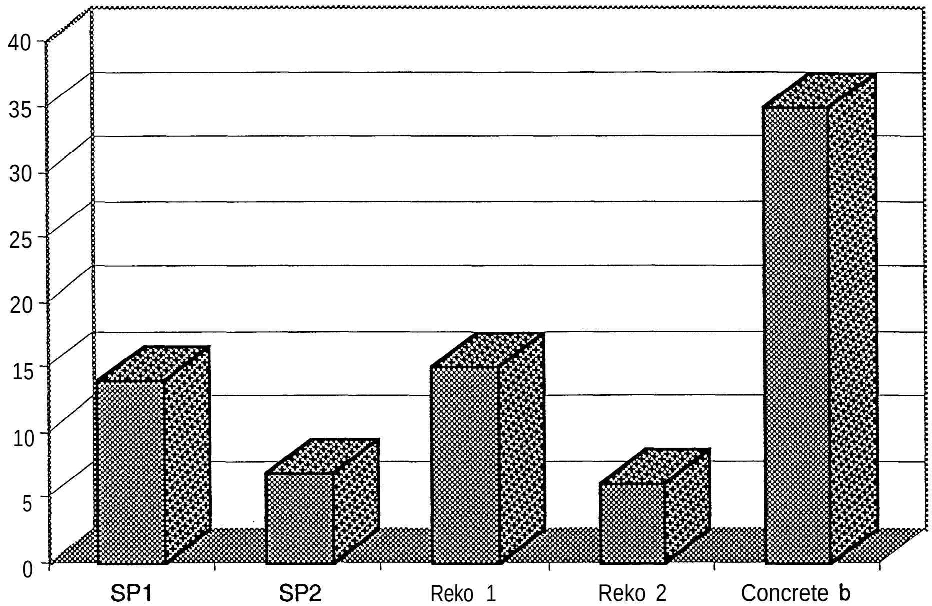

Fig. 2 - List of contents in dissolved organic carbon (DOC) in eluates from concrete specimens (broken material). Specimens which contain only SPs (SP 1 = naphthalene sulphonate polymer, SP 2 = melamine sulphonate polymer) are compared with concrete granulate specimens (Reko 1 and 2) and coated concrete demolition material. SP specimens contain 4% active substance in relation to the cement weight.

Concrete demolition material is stored in heaps in the open until it is reused (Fig. 3). As concrete admixtures have only found widespread use in about the last 30 years, it can be assumed that the concrete demolition material currently becoming available should in large part be free of concrete admixtures. In order to be able to estimate future emissions from the leaching of SPs, tests were carried out with test specimens with a defined SP content. If the total quantity of concrete demolition material (SPs at today's batching rate) becoming available yearly in the Canton of Zurich is stored in the open, max. 300 kg of SPs in total can be leached each year by precipitation falling upon it. Similar considerations with the use of concrete granulate in unbound form for road beds (Fig. 2) show emissions of max. 900 kg of SPs a year for the whole Canton of Zurich, These emissions would in the worst case (assumption: there is no degradation) lead to measurable concentrations of organic compounds of max. 0.2 mg DOCA in the ground water immediately below the heaps and roads in question.

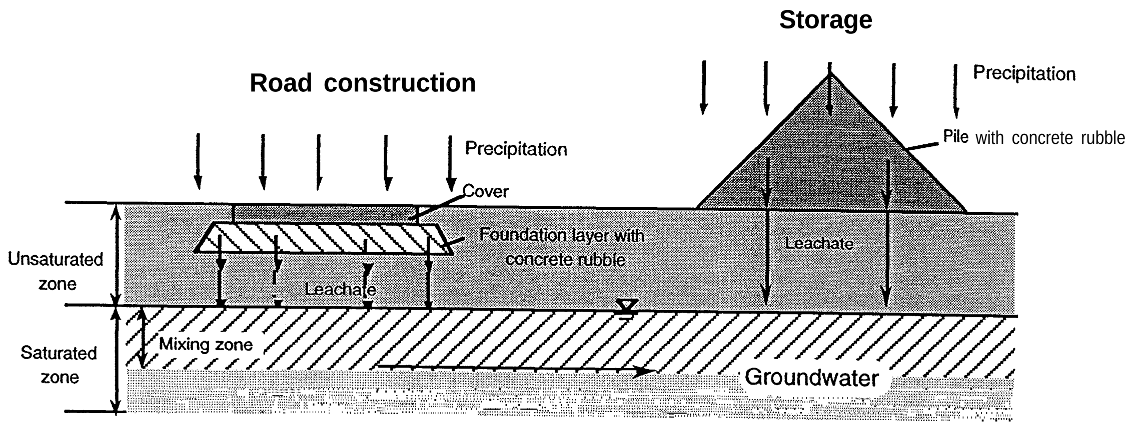

Fig. 3 - Typical scenarios with occurrence of precipitation when storing concrete demolition material or granulate (right) and when using processed concrete demolition material as road bed (left).

These estimates are based on very unfavourable assumptions. If one considers, for example, the guidelines issued by the Canton of Zurich for the use of secondary building materials [6] the emissions to be expected should be less by l-2 orders of magnitude.

Swiss legislation on waste [TVA, 7] stipulates that building waste must be recycled if possible. Concrete granulate is mostly used in hydraulically bound form as a substitute for gravel. The question therefore arises of whether an accumulation occurs with the repeated recycling of concrete with the addition of concrete admixtures. Calculations show that at most a doubled content results with a proportion of 70% concrete granulate in the aggregate (assumption: infinitely many recyclings).

No problems arising from SPs are to be expected when dumping concrete demolition material as an inert substance in compliance with legislation (TVA).

4.2 Risk assessment summary

On the basis of existing data and estimates the superplasticizers under consideration can hardly be classified as ecologically hazardous from the point of view of environmental technology, With correct use and disposal of SPs no adverse effects are to be expected for the health of man and environment. As the concrete admixtures are very readily soluble in water, no accumulation is to be expected in soils, water-bearing strata or organisms, The products used as SPs are also used in significantly greater quantities in other sectors, Caution is therefore required in the interpretation of measurement data, for example when it comes to waste water.

IV. Measures for improving environmental compatibility

Emissions which lead to significant burdening of the environment must be reduced to a compatible level. In principle a distinction is made between three categories of measure:

- Information and recommendations (e.g. recommendations on on-the-job safety)
- Safety measures (e.g. taking-back of product residues)
- Reduction (e.g. restrictions on use)

In general measures to improve the environmental compatibility of these products should be taken where the greatest emissions are to be expected, In the case of ready-mixed concrete wash water is increasingly being reused as gauging water and unused concrete is being mixed and used again with fresh concrete.

Of the sources of emission discussed here leaching during storage should have the greatest potential effects on the environment. In the context of precautionary measures therefore care should be taken that yards where concrete demolition material is stored are drained and the drained water led off to a purification plant.

The incorporation of concrete demolition material in road foundations should be far less relevant. In order here too to minimize emissions into ground water, the concrete demolition material should as far as possible be used in bound form. This reduces the amount of water infiltrating and thus emissions into the subgrade,

5. A look into the future

Even if the database for concrete admixtures can be described as good compared with other products the knowledge gaps still found during this study have been partially completed. The following questions are dealt with in particular:

How quickly do concrete admixtures decompose in concrete?
How is the leaching behaviour of concrete admixtures from intact concrete structures?

In another step environmental compatibility is to be balanced against the benefit of concrete admixtures, which will allow an overall assessment of concrete admixtures. New products are in future to be assessed in accordance with the above-mentioned procedure and taking into account the experience gained.

References

1. EU Order 793/93
2. EU Directive 67/548 incl. adaptations and amendments
3. Order on ecologically hazardous substances (1986)
4. FSHBZ. Environmental compatibility of concrete admixtures (1 st version 1995)
5. Federal Office for Energy Management. Pollutant emission behaviour of building materials (1995)
6. Directorate of Public Buildings of the Canton of Zurich. Guidelines for the ecological use of secondary building materials in superstructure and in subgrade stabilizers of roads, paths and squares
7. Technical Ordinance on Waste (1 July 1994)

Indoor Environment and sustainable development
Toward a more ascetic way of living

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Abstract :

The problem of a building compatible with sustainable development involves the adequation of four factors :

The increase of the world human population
The increasing level of comfort
The consumption of resources to achieve this level
The disponibility of these resources on Earth

Until today almost all the efforts to solve the problem have been concentrated on the third factor.

It is rational to examine the possiblity to act on the others.

Here it is proposed to examine the possibility to lessen the level of comfort in buildings. Indoor temperature has been legally lowered in the 70s.

People lived in less comfortable situations in the past centuries. Is it a step-back today feasable?

A. Generals

A.1. Man is a factor of concern to the future of this planet. Are we conscious really that he rivals with large volcanos in the matter of atmospheric pollution and has no rival at all for water pollution and natural products' consumption ?

His action is growing worst for two facts :

- its multiplication,
- the increase in the level of his comfort and commodities requirements.

The consequences of these two facts are :

- increase in pollution of all kinds, arithmatically speaking - two billion people pollute twice as much as one billion,
- increase in consumption of building materials largerly based on natural resources,
- increase in the energy used to exploit buildings.

A.2. The multiplication of men is frequently evocated - and its amplitude discussed.

An optimistic view is that this expansion will stop in some decennies after the doubling of the population. In reality nobody knows, and some prudent (and exposed) countries have taken measures, with more or less luck.

This point will not be dealt with further here.

But the other point : the increase in building comfort and commodities has practically never been dealt with.

Nevertheless, it is a really important point :

From a rough approach we can conclude that : of the actual population a tenth only enjoy the level of comfort and commodities we know in the middle class of the affluent countries, half of the rest consumes half of this level, and the rest a fifth.

Thus if the world population doubles and if it should reach the level of standard of living of the affluent countries, the consumption will be multiplied by five.

A.3 This rise in consumption concerns energy as well as building products. The last mobilises enormous quantities of products and wastes - in construction, exploitation and demolition.

A consequence of all that is that, if reasonable, we should think over the problem under this form : What standard of comfort and commodities' level is compatible, on Earth, with the sustainable development ?

And if you write levels in place of level, imagine the problems.

B. The standard of life level of the human beings in their habitation - Its evolution

B.1 In the affluent countries, the housing energy consumption consists in :

- Heating in cold seansons, air conditionning in hot seasons
- Using sanitary hot water
- Cooking
- Lighting without restrictions nor savings
- Using home and offices equipments.

The sum gives energy expenses of about a yearly 2 Tep (Equivalent oil ton) per home.

As for the volume of constructions, the UN-ECE Compendium of Model Provisions for Building Codes set a minimum area of 12 to 14 m2 of living space per inhabitant.

And the volume of housing construction in a country is roughly equal to that of constructions of other types.

The move towards more comfort is natural.

Thus in France since the beginning of the century, the duration of the heating period passed from 4 months to 5 in 1950 to 8 months today.

One room and the kitchen were heated. Today we enjoy central heating.

And the "clim" (air conditionning) is invading every type of buildings.

The home and office equipments rised from zero to all we enjoy today.

Etc. etc.

And people certainly appreciate all this progress.

But it is continuing :

A demand for more heat comfort doesn't really exist, but new building equipments are appearing which, in general, people accept and which power distributors and manufacturers push for. And, as a common law, no brake exists.

On another hand, less rich people in less rich countries ambitionnate to reach the level of comfort standards of the affluents.

A question is clearly evident :

Are the moves toward more comfort in the rich countries,

and the move of the less rich or poors toward the level of the rich,

are these moves compatible with the sustainable development ?

To answer this question requires :

- Forecastings about volume of populations and level of consumptions linked to the living comfort (but it is always difficult to forecast, especially the future...)

Estimating the level of future energy resources, the mass of natural resources man can exploite without endangering the sustainable development.

But is the concern justified ?

The optimists will say : "The increase in population will stop spontaneously, man will develop new energy sources, non polluting and unlimited, like nuclear fusion or cover the deserts with solar collectors. And all is good - Maybe, maybe not.

It is not reasonable to, at least, study what could be done to face the difficulties, if and when necessary.

In short, to study how and how far, by the means to reduce consumptions to catch a given level of comfort, it is possible to lessen the level of comfort, itself. Id est to live in a more ascetic way than today in affluent countries.

C. Thinking over the problems

Three ways of lowering the standard of living exist :

Coercision

Conviction

Cost correlations, which in fact back stop the two first.

Advanced countries have lived since the 1970s an episode of such lowering :

These countries have been confronted with the necessity, for national economic reasons, to lower their oil consumption. They imposed to lower the winter heating reference operative temperature of 20°C to 19°C. The economy was remarquable : in France about 0,2 Tep per home.

The measure was accepted (which does not mean respected) because people faced a private economic problem. So they accepted to wear a sweater at home, to cut down the heating bill.

But other measures could not be as easily accepted :

The necessary restrictions of air conditionning will face the opposition of the building occupants, of the air conditionning industry, and of the power distributors.

To overcome the obstacle it seems to be necessary to sensitize the people to the problems of sustainable development, to use a lot of coercition, probably under the form of taxations. That people and governments take unpleasant measures for the sake of solving problems of coming generations lies in the field of Vitruve...

What could be envisaged is a study to find the possible restrictions in comfort :

- room temperatures, warm water consumption, dimensions of the rooms, etc. and to disseminate a guide for people concerned with sustainable development.

- to examine the best way - under the form of regulatory obligations, or tax actions, to enforce the corresponding measures.

Classification of Finishing Materials '95

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Abstract

The purpose of the Classification of Finishing Materials '95 is to set emission requirements for the materials used in common living and work spaces to achieve good indoor air quality. The goal is to enhance the use and development of low-emitting materials.

The Classification of Finishing Materials has three categories, category M1 being the best and category M3 containing materials with highest emission rates and materials that are not tested. Because total emission and concentration in room air depend on the amount of used materials, the Classification gives guidelines for the use of various materials.

Category M1 is designated for natural materials, such as stone and glass, which we know to be safe in respect of emission and for materials that fulfil the following requirements:

- emission of TVOC is below 0.2 mg/m2h
- emission of formaldehyde is below 0.05 mg/m2h
- emission of ammonia is below 0.03 mg/m2h
- emission of carcinogenic compounds (due to IARC) is below 0.005 mg/m2h
- material is not odorous

Until December 1997 The Building Information Institute has classified 127 finishing materials. Several houses are being built, in which finishing materials have been selected according to the Classification of Finishing Materials.

Keywords: Indoor air, finishing materials, classification, emissions, odours

Introduction

In its meeting of 4 October 1995, the Board of Directors of The Building Information Institute, BII, established Committee TK 185 to study indoor air quality, construction works, and finishing material classifications. Committee TK 185 is responsible for maintaining and developing classifications for indoor air quality, construction works, and finishing materials based on procedures established in the Indoor Air Association Classification Bulletin No. 95. It is the committee's continuous responsibility, aside from determining to which class a material belongs based on the specifications provided, to reach decisions relating to detailed classification procedures such as testing frequency and the formulation of laboratory testing requirements. Additionally, the Committee monitors the use of classification symbols in marketing and takes legal action to correct any possible abuses.

These instructions, approved by BII committee TK 185 in its meeting of 27 February 1996, describe the principles underlying emissions classification procedures.

Proof of Classification of Finishing Materials

Emission classifications are defined in Classification of Finishing Materials Bulletin - ML 95 (15 June 1995). Classification requires an approved testing report conducted according to required procedures.

Requirements for Finishing Materials

Category M1 is designated for emission tested materials whose emissions fulfill the following requirements:

- emission of TVOC is below 0.2 mg/m^2h;
- emission of formaldehyde (H_2CO) is below 0.05 mg/m^2h;
- emission of ammonia (NH_3) is below 0.03 mg/m^2h;
- emission of carcinogenic compounds according to category 1 IARC classification is below 0.005 mg/m^2h;
- the material is not odorous (dissatisfaction with the odor is below 15%)

Category M1 includes also natural materials which are known to be safe in respect of emissions:

- brick
- natural stone and marble
- ceramic tile
- glass
- metal surfaces
- board and log (Finnish wood) whose emissions as fresh, however, may be higher than those specified for materials of category M1.

Category M2 is designated for emission tested materials whose emissions fulfill the following requirements:

- emission of TVOC is below 0.4 mg/m^2h;
- emission of formaldehyde (H_2CO) is below 0.125 mg/m^2h;
- emission of ammonia (NH_3) is below 0.06 mg/m^2h;
- emission of carcinogenic compounds according to category 1 IARC classification is below 0.005 mg/m^2h;
- the material is not strongly odorous (dissatisfaction with the odor is below 30%)

Category M3 includes materials which do not have emission data or the emissions exceed the values specified for materials in category M2.

Application

Classifications' of finishing materials are granted by BII. The application and its supporting documentation is to contain the product's function, trade names and the

Testing Procedure

Sample selection, analysis, and material emissions measurements shall be undertaken according to procedures specified in *European Data Base on Indoor Air Pollution Sources in Buildings. Protocol for testing of building materials.* Odour-related emission measurements shall be conducted according to *Odour Emission Measurement Instructions for Surface Materials.*

If Flec chambers are used in chemical testing, a control sample shall be simultaneously measured for ageing and odour-related evaluation in applicable chambers.

Products are tested for the following properties:

- total volatile organic compounds TVOC,
- formaldehyde H_2CO,
- ammonia NH,
- carcinogens and
- odours.

Selection of testing laboratory

Sample selection, analysis, and material emissions measurements shall be undertaken according to product group acceptance principles by an impartial and competent laboratory with quality assurance adhering to such standards as SFS-EN IS0 9003. Accredited laboratories may be recommended for use.

Product marking

When classification has been granted, products, packaging, product specifications, and instructions for use are marked with classification symbols Ml, M2, or M3.

Additionally, product specifications shall specify any possible limitations for product use or application conditions that would serve to increase emission levels such as:

- application conditions, applicability.
- base requirements (moisture, temperature).
- preliminary treatment.
- operational safety.
- packaging.
- transportation (packaging).
- storage (storage conditions, i.e. packaged, wrapped in plastic).
- use and installation instructions.
- cleaning directions (detergent pH requirements).
- environmental protection and waste treatment.

Product marketing

Classification symbols may be used in advertising and marketing for specific products. Classification symbols may not be used in marketing to create the impression that an entire company or all of its products are classified.

Filing Appeals

Companies wishing to appeal decisions rendered by BII concerning user rights or their rejection may file an appeal in written form within **14** days from the date the decision was received to BII's representative, who will forward it to Committee TK 185 for adjudication.

Directory

BII maintains and publishes a directory of currently valid classified products and holders of user rights.

Table 1. Directory of 127 classified products.

Category Ml

31 Concrete products

Suomen Siporex Oy

- Siporex tempered aerated concrete

36 Building boards

Gyproc Oy

- Gyproc extra-hard indoor decorative panel GEK 13 O/N
- Gyproc normal indoor decorative panelGN 13 O/N
- Gyproc renovation panel GN 6 0
- Gyptone Acoustics panel, unpainted
- Gyptone Acoustics panel, painted

Knauf-Kipso Oy

- Danogips Acoustics panel, unpainted
- Danogips Acoustics panel, painted
- Knauf- Kipso extra-hard indoor decorative panel KEK
- Knauf-Kipso normal indoor decorative panel KN
- Knauf-Kipso renovation panel KS

Hackman Sisustus Oy

- Hovi roof sheet
- Kartano roof sheet

Hackman Sisustus Oy

- Ritilä roof sheet
- Tupa roof sheet
- Juutti wall sheet
- Jäkälä wall sheet
- Leija wall sheet
- Naava wall sheet
- Piennar wall sheet
- Raitti wall sheet
- Rohdin wall sheet
- Säde wall sheet
- Tuohi wall sheet
- Saturnus wall sheet
- Jupiter wall sheet
- Hovi tongued and grooved roof sheet

Isover Oy

- AKUSTO-Classic
- AKUSTO-Fantasy
- AKUSTO-Symphony
- AKUSTO-Melody
- AKUSTO-Twist
- AKUSTO-Jazz

Partek Paroc Oy Ab

- Fjord acustical sheet

Schauman Wood Oy

- WISA-Birch birch plywood
- WISA-Spruce pine plywood
- WISA-Form birch plywood, surface of phenol

Suomen Kuitulevy Oy

- Huokoleij ona
- Leij ona-Kovalevy, hard board, painted
- Leij ona-Seinälevy, wall sheet
- Runkoleij ona

37 Insulation Products

SPU-Systems Oy

- SPU-thermal insulation product

53 Flooring

Tarkett Oy

- Standard Plus
- Optima

Eminent
Eminent 4,0
Granit Antistatic
Optima 4,0
SuperNova

Forbo Oy
Artoleum
Colorex
Marmoleum 2.0
Marmoleum 2.5
Marmoleum Foam
Multistep
Novilon
Onyx
Prisma
Scandilon
Smaragd Aqua
Smaragd Classic
Smaragd Nature
Smaragd Plus
Smaragd Relief
Surestep

Paloheimo Parquets Oy
Lamella Tammi Parquet

Centennial Oy
ARC 791 V surface of quartz composition

Upofloor Oy
Estrad
Estrad Antistaat
Estrad dB
Estrad Grip
Estrad Ohmi
Estrad Plano
Domostep
Finntile
Hovi
Remppa
Upostep 20

54 Wall finishes

Decocoat ky
Decocoat natural fibrous surfacing

Sandudd Oy
Sandudd wall paper
Otto wall paper

Borastapeter AB
Moment wall paper

55 Plaster, rendering

Tikkurila Paints Oy
Prestonit K
Prestonit T

Optiroc Oy
Gyproc screed
Gypsum plaster
Vetonit ground plaster L
Vetonit surface plaster LR
Vetonit tile plaster
Vetonit
Vetonit VH

Basok Oy
Breplasta F
Breplasta J
Breplasta S
Breplasta LF ja LF+
Breplasta LG
Breplasta LGS
Breplasta SR

56 skirtings, profiles, tapes, glues

Kiilto Oy
Kiilto wall and floor glue M 1000

58 Paints and varnishes

Tikkurila Paints Oy
Novaplast 20
Siro 20
Novaplast 2
Siro Grund
Remontti-Ässä
Dickursby väggfärg akrylat 20
Valtti Ace
Eko-Joker
Novaplast 7
Siro 7
Siro dim plus
Assaplast 2
Assaplast 7

Teknos Winter Oy
Alcyd infill
Biora 3 roof paint

Biora 7 wall paint
Remontti-Biora 20 renovation paint
Ekora 3 ground paint
Ekora 7 indoor paint
Ekora 12 indoor paint
Ekora 20 renovation paint
Mestari renovation paint
Natura varnish
Tela 3 ground and ceiling paint
Tela 7 wall paint
Tela 20 renovation paint

Kiilto Oy
UNO-parquet varnish

Category M2

No classified products

Category M3

Category M3 includes materials which do not have emission data or the emissions exceed the values specified for materials in category M2.

References

1. Classification of Finishing Materials. General Instructions. The Building Information Institute. 27 February 1996.
2. European Data Base on Indoor Air Pollution Sources in Buildings. Protocol for testing of building materials. Version 1 .0, November 28, 1995.
3. Indoor Air Quality, Construction Works, and Classification of Finishing Materials. Interior Climate Association, 15 June, 1995.
4. Nordtest, Building Materials: Emission of Volatile Compounds - Field and Laboratory Emission Cell, Draft Nordtest Method 93-l O-l 3.
5. Odour Emission Measurement Instructions for Finishing Materials. February 27, 1995. University of Technology, HVAC laboratory, 1996.

Reported health problems and indoor environment in single-family houses

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Abstract
The objective is to investigate the relationship between self-reported health problems and complaints of the indoor climate, and building characteristics and physical indoor climate in single-family houses.

Data collected from 781 single-family houses are used. These data consist of building characteristics collected from on site inspections, indoor climate measurements (temperature, ventilation, humidity of indoor air) and the residents' perceptions of their indoor climate and health obtained from postal questionnaires. A group of 77 single-family houses, in which the residents reported complaints and symptoms at enhanced rates is compared to 704 randomly selected single-family houses.

The principal finding is a significant association between complaints and symptoms and water/mould/rot damage. Complaints and symptoms are also more frequent in houses grounded on concrete slab and in homes with wall-to-wall carpets. Hence, this study support evidence that moisture may cause health problems in single-family houses. This study also indicates that reported allergic disorders, complaints and symptoms are positively correlated. Controlling for allergic disorders, the results remain. We do not find any correlation between perceived and measured indoor climate, however.
Key words: building characteristics, complaints, health problems, indoor climate, moisture, single-family houses.

1 Introduction

In Sweden as well as in most of the developed countries a dramatic improvement of the housing conditions have taken place. Nevertheless, health problems are still experienced in office buildings, schools and residential buildings. Sick Building Syndrome (SBS) has become a common term in indoor environment research. SBS includes a combination of general symptoms and symptoms of mucosal membranes and skin. Moreover, it is implied that the symptoms are related to residence or work in a certain building.

The phenomena of SBS and building-related illness/symptoms have been subject to intense research during the last decades. Still, no specific factor or agent causing SBS or building-related illness has been proven. However, certain environments have been suspected to increase the risk for SBS or health problems, especially damp buildings [1,2,3,4,5,6]. Several studies report associations between type of ventilation system, especially modern systems with humidifiers, and symptoms in office buildings [7,8,9,10]. The results are inconclusive, however, and reports of association between air flow rates and health are scarce [11,121.

Only a few statistically representative cross-sectional studies of national scope have been carried out in order to estimate the extent of SBS and building-related health problems. One of them, the ELIB-study [13], indicated that 600,000 to 900,000 Swedish residents, or about 10% of the population, were exposed to indoor climate in their residences that may affect their health and well-being.

The ELIB-study concluded that complaints about the indoor climate and symptoms were more frequent in multi-family houses compared to single-family houses. However, the physical indoor climate was less favourable in single-family houses compared to dwellings in multi-family houses. In spite of lower frequencies, there are obviously residents in single-family houses who are dissatisfied with their indoor environment and also experience some health problems. Are their houses or the households different in any way?

The specific questions to be discussed in this paper are:

- Are single-family houses in which many residents complain about the indoor climate or report health problems technically different than other houses?
- Are the indoor environment different?
- Is dampness a common factor in those houses?

2 Method

The data used in this study were collected in the ELIB-study [13]. They consist of physical measurements of indoor climate, technical data of building characteristics and data of perceived indoor climate and symptoms.

Measurements of the indoor climate were all of passive integrating type. Monthly averages of temperature, relative humidity and ventilation rate during the heating season were calculated.

Technical inspections on site were performed by technical consultants using a special inspection form. The data included type, age and condition of the building, structural and thermal insulation characteristics, ventilation system, heating system, indicators of moisture problems, and housing characteristics.

The postal questionnaire was developed at the Department of Occupational and Environmental Medicine at the Örebro Medical Centre Hospital [14]. The questionnaire asked the residents about the perception of 11 indoor climate factors and 12 symptoms, see Table 1. The recall period was three months. Three alternative answers were given: "Yes, often (every week)", "Yes, sometimes" and "No, never". The answer "Yes, often" is interpreted as that the trouble or symptom exist.

The total number of single-family houses in the study is 78 1. Based on the results of the questionnaire 77 single-family houses were identified in which at least one of the occupants reported three complaints or more of indoor climate or at least two symptoms. Of the remaining 704 single-family houses in which the residents not had enhanced rates of problems with indoor environment or health problems there were 233 houses in which the occupants had no complaints or symptoms at all. Thus, the three study groups are: "problem houses"(77), "reference houses"(704), and "problem-free houses"(233), see Table 1.

As the criteria for categorising the houses is determined by the residents response to questions about perception of indoor climate and symptoms, important personal related variables in the analysis are made on summary measures of individuals in the households.

In the univariate statistical analysis we cross-tabulate the three groups of houses against the variable of interest in nominal, ordinal or interval scale. Some significant risk and control variables identified in the univariate analysis are then included in two multiple logistic regression models. The independent variables are the same in both models but the outcome in the first logistic model is the binary variable of problem house (value=l) vs. reference house (value=O) and in the second model problem house (value=l) vs. problem-free house (value=O).

3 Results

The proportion of women living in the problem houses is 50%. In the reference houses and in the problem-free houses the proportion of women is 48%. There is a significantly greater proportion of younger people (<40 years of age) in the problem houses compared to the other types of houses. Also, there is a significantly greater proportion of residents suffering from allergic disorders in problem houses compared to the other types of houses. Table 1 shows the proportion of residents answering "Yes, often" to the questions about indoor climate complaints, "Yes" to the questions about allergic disorders, and "Yes, often" to questions about symptoms. The criteria for categorising the houses is reflected in the substantial differences in frequencies of complaints and symptoms.

Variable	Individuals (%) in		
	Problem houses	Reference houses	Problem-free houses
Draughts	6.8	2.0	1.3
Too high room temperature	1.5	1.9	0.8
Varying room temperature	9.8	2.8	1.3
Too low room temperature	6.8	1.5	0.3
Stuffy air	6.7	2.2	0.0
Dry air	15.8	4.0	1.5
Unpleasant smells	5.2	1.5	0.0
Static electricity	1.5	0.4	0.3
Passive smoking	7.5	1.9	0.5
Noise	3.7	0.6	0.3
Dust and dirt	9.8	2.0	0.3
Asthmatic problems	19.1	6.3	5.5
Hay fever	21.2	12.6	9.1
Eczema	20.5	14.2	11.1
Fatigue	26.2	8.2	4.7
Feeling heavyheaded	11.6	2.9	1.1
Headache	11.7	3.4	0.8
Nausea, dizziness	6.1	0.6	0.0
Concentration difficulties	3.1	0.6	0.0
Eye problems	6.8	1.8	0.8
Nasal problems	22.5	4.4	1.3
Hoarseness or dryness in the throat	8.5	1.8	0.5
Coughs	7.0	1.7	0.3
Facial skin problems	12.3	2.6	1.0
Itchy scalp	8.5	4.2	0.8
Skin problems on hands	10.0	2.6	2.4
Number of houses in the sample	77	704	233

Table 1. Proportion of individuals reporting complaints of their indoor climate and suffering from allergic disorders and symptoms.

Many of the building and housing characteristics are similar in the studied houses, see table 2. However, some differences may be noted. Moisture damage is more common in problem houses. It also seems as the problem houses are more crowded and built on slab on the ground to a greater extent. Urban localisation of the houses as well as rented ownership are more common among problem houses.

As can be seen from table 3 there are no major differences in mean values and medians of climate measurements between reference houses and problem houses. However, the mean value of ventilation rates, expressed as l/s,person, is somewhat lower among problem houses compared to reference houses and problem-free houses (not significant though). Single-family houses with problems appear to be slightly newer than the reference houses (p-value=0.06).

Variable	Value	Single-family houses % Problem	Reference	Problem-free
Type of building	Detached houses	74.0	80.0	82.4
	Terraced houses	10.4	11.1	10.3
	Linked or semidetached houses	15.6	8.9	7.3
Type of ownership	Tenancy	7.8	6.0	* 2.1
Area of localisation	Urban	83.1	* 73.3	77.7
Number of residents	1	3.9	* 11.4	* 12.0
	2	23.4	* 38.2	* 46.4
	3	24.7	* 16.8	* 15.0
	4	28.6	* 22.0	* 18.9
	5-7	19.5	* 11.6	* 7.7
Type of foundation	Cellar, split-level	45.5	* 47.3	* 51.9
	Crawl-space	14.3	* 27.1	* 22.3
	Slab on the ground	40.3	* 25.6	* 25.8
Type of soil condition	Solid rock	15.6	13.4	13.3
	Clay	31.2	31.1	30.5
	Other	53.2	55.5	56.2
Heating system	Furnace	51.9	58.0	62.7
	Direct electrical heating	27.3	25.4	21.5
	Other	20.8	16.6	15.9
Ventilation system	Natural	66.2	73.9	73.0
	Exhaust	20.8	16.3	15.5
	Supply-and-exhaust	13.0	9.8	11.6
Moisture damage in attic	Yes	10.4	9.3	5.6
Moisture damage in basement	Yes	24.7	17.3	17.2
Moisture damage in wet spaces	Yes	19.7	16.8	14.7
Other moisture damage	Yes	14.3	* 4.5	* 3.1
At least one moisture damage	Yes	46.8	35.7	* 31.3
Condensation on window	Yes	28.6	28.0	26.2
Unpleasant smell	Yes	15.8	17.6	12.9
Wall-to-wall carpet	Yes	57.9	51.3	51.9
Noise	Yes	7.8	5.4	3.4

*Table 2. Frequencies (%) of houses with certain building and housing characteristics. * denotes a significant difference compared to problem houses on the 5% level.*

Variable	Mean Problem	Reference	P-f	Median Problem	Reference	P-f
Outdoor temperature	1.9	1.7	1.8	2.3	1.9	1.9
Outdoor humidity, g/m3	3.8	3.7	3.8	3.8	3.7	3.8
Ventilation, l/s,m2	0.26	0.24	0.23	0.23	0.21	0.20
Ventilation, l/s,person	12.2	14.2	14.8	10.0	11.1	12.0
Ventilation, air-changes/h	0.38	0.35	0.34	0.35	0.31	0.30
U-value, wall	0.42	0.39	0.38	0.34	0.33	0.33
U-value, attic	0.28	0.28	0.27	0.25	0.25	0.25
Indoor temperature	21.2	21.2	21.1	21.2	21.2	21.1
Indoor relative humidity	39.5	38.9	40.0	38.5	38.0	39.0
Construction year	1961	1954	1959	1971	1965	1966

Table 3. Physical indoor climate measurements in reference, problem, and problem-free houses (P-f).

In the multiple analysis we find the following risk variables significantly associated with occurrence of high rates of complaints and health problems: At least one moisture/mould/rot damage in the house, number of allergic disorders in the household and living space. In addition, foundation by slab on the ground and wall-to-wall carpets are significant in the model comparing problem houses to problem-free houses. Variables included in the model as control variables and confounding variables are: Year of construction (-1940, 1941-60, 1961-75, 1976-), area of localisation (rural, urban), type of ventilation system (natural, exhaust, supply and exhaust), average age of residents in the home and indoor temperature.

Factors	**Odds Ratios (CI)**	
	Reference	Problem-free houses
Foundation by slab on the ground	1.80 (0.89-3.65)	2.40 (1 .OO-5.75)
# Allergic disorders in household	**1.67** (1.25-2.22)	**1.78 (1.22-2.58)**
Space (m^2 /person)	0.98 (0.96-0.99)	0.97 (0.95-0.99)
Wall-to-wall carpet	1.71 (0.93-3.15)	**2.17 (1.03-4.57)**
At least one moisture damage	2.09 (1.14-3.85)	3.60 (1.66-7.83)
Ventilation rate, l/s,person	1.03 (0.99-l .06)	1.03 (0.98-l .09)
Indoor relative humidity	1 .OO (0.96-l .05)	0.99 (0.93- 1.04)

Table 4. Adjusted odds ratios and 95% confidence intervals for the association between a house classified as a problem house and risk factors.

4 Discussion

In the multiple logistic regression analysis the associations between occurrence of at least one moisture damage and enhanced rates of complaints or health problems are significant, with odds ratios of 2.09 (1.14-3.85) and 3.60 (1.66-7.83), respectively. The physical indoor climate is, however, not significantly associated with enhanced frequencies of complaints or health problems, but indoor temperature, relative humidity and ventilation rate might act as confounders and/or effect modifiers. In Sweden high relative humidity indoors during winter time is unusual. The mean RH in single-family houses is just below 40%, and the values range from 21% to 80%, with just a few values above 60%. Associations between relative humidity and respiratory symptoms has been found in but a few of the studies made, more often these association are not proven [4]. In spite of dry air, problems from moisture still may occur due to air tightness and long time spent indoor during winter time [5]. Thus, it is not surprising to find that relative humidity is not significantly correlated with enhanced rates of complaints and symptoms. Different distributions of constructing year, area of localisation, ventilation system and age of the residents are controlled for by including these variables in the two models.

According to table 1, the frequencies of allergic disorders are much higher among residents in problem houses. Furthermore, the frequencies of allergic disorders are lowest among residents in problem-free houses. It might be so that many of those who report symptoms have got their symptoms from allergic disorders. Thus, occurrence of allergies must be controlled for in a model to describe the relationship between indoor climate and symptoms. The odds ratio for number of allergic disorders in the household is significant and slightly higher in comparison with problem-free houses.

With this type of cross-sectional sample survey we may have problem with selection bias. People with many symptoms and/or people with a tendency of complaining may have a tendency to live in houses with certain characteristics. Factors that may influence the way of how to choose, or be forced into standards of living are, e.g. age, family status, disposable income, employment, chronically diseases and allergic disorders. By controlling for these types of variables one may overcome some of the problems with selection bias. In this study we are only able to consider age and allergic disorders. In a forthcoming study we are going to consider other socio-economic variables as controls.

Some alternative multiple logistic regression models has been tested to assess the importance of certain variables and the stability of estimated coefficients of the main variables. The significant variables allergic disorders, space and moisture damage remains stable, but if ventilation rate is deleted from the model the estimated coefficients change somewhat. Comparing the model log-likelihood for the alternative models concludes a significant impact of ventilation rate on parameter estimates.

For testing if the estimated model is sensitive to the included observations, two independent samples from the available data set has been drawn. The sample sizes are 90% in both cases. The estimated coefficients does not change dramatically, and the conclusions from those models are the same.

The most important result from this study is that moisture damage based on inspection is an important factor for high rates of complaint and health problems. Comparing problem houses to problem-free houses strengthen this tendency. Households with many complaints and health problems are more frequently found in houses built on concrete slab and in apartments with wall-to-wall carpeting.

The approach to define houses as problematic or “sick” on summary measures of symptoms and complaints has limited value for assessment of the aetiology of building related health problems [15]. Various symptoms and complaint patterns has probably its own risk factors. In the ELIB-study we collected many variables related to dampness in the buildings which are to be analysed with respect to certain groups of symptoms and individual symptoms. Moreover, selection bias, living conditions and different socio-economic factors should be studied more thoroughly. This will be done in further analysis of this data, along with a systematic assessment of interaction.

References

1. Platt, S., Martin, C., Hunt, S., and Lewis, C. (1989) Damp housing, mould growth, and symptomatic health state. *British Medical Journal*, Vol. 298, pp. 1673-1678.
2. Dales, R.E., Burnett, R., and Zwaneburg, H. (1991) Adverse health effects in adults exposed to home dampness and molds. *American Review of Respiratory Disease,* Vol. 143, pp. 505-509.
3. Spengler, J., Neas, L., Nakai, S., Dockery, D., Speizer, F., Ware, J., and Raizenne M. (1994) Respiratory symptoms and housing characteristics. *Indoor Air,* Vol. 4, pp. 72-82.

4. Husman, T. (1996) Health effects of indoor-air microorganisms. *Scandinavian Journal of Work Environment and Health,* Vol. 22, pp. 5-13.
5. Pirhonen, I., Nevalainen, A., Husman, T., and Pekkanen, J. (1996) Home dampness, moulds and their influence on respiratory infections and symptoms in adult in Finland. *European Respiratory Journal,* Vol. 9, pp. 26182622.
6. Williamson, I. J., Martin, C. J., McGill, G., Monie, R.D.H., and Fennerty, A.G. (1997) Damp housing and asthma: a case-control study. *Thorax,* Vol. 52, pp. 229- - 234
7. Skov, P., Valbjörn, O., Pedersen, B.V., and DISG. (1989) Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome. *Scandinavian Journal of Work Environment and Health,* Vol. 15, pp. 266-295.
8. Hedge, A., Burge, P.S., Robertson, A.S., Wilson, S., and Harris-Bass, J. (1989) Work-related illness in offices: A proposed model of 'sick building syndrome'. *Environment International,* Vol. 15, pp. 143-158.
9. Zweers, T., Preller, L., Brunekreff, B., and Boleij, J.S.M. (1992) Health and indoor climate complaints of 7043 office workers in 61 buildings in the Netherlands. *Indoor Air,* Vol. 2, pp.127-136.
10. Jaakola, J.J.K., Miettinen, P., Tuomaala, P., and Seppänen, 0. (1993) The Helsinki office environment study: The type of ventilation system and the 'sick building syndrome'. *Proc. of the 6th International Conference on Indoor Air Quality and Climate, Indoor Air* '93, Vol. 1, Helsinki.
11. Sundell, J. (1994) On the association between building ventilation characteristics, some indoor environmental exposures, some allergic manifestations and subjective symptom reports. *Indoor Air Suppl.,* Vol. 2, pp. l-42.
12. Godish, T., and Spengler, J.D. (1996) Relationships between ventilation and indoor air quality: a review. *Indoor Air,* Vol. 6, pp. 135- 145.
13. Norlén, U., and Andersson, K.(eds) (1993): *The Indoor Climate in the Swedish Housing Stock.* D 10: 1993, Swedish Council for Building Research, Stockholm.
14. Andersson, K., and Stridh, *G.* (199 1) *The use of Standardized Questionnaires in BRI/SBS surveys.* Pilot Study on Indoor Air Quality, Oslo, Aug. 1991.
15. Hedge, A., Erickson, W.A., and Rubin, G. (1996) Predicting Sick Building Syndrome at the Individual and Aggregate Levels. *Environment International,* Vol. 22, pp. 3-19.

Natural Convection within a Rectangular Enclosure in a Window Construction (A Numerical Study)

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Abstract

The windows are important parts of the building shield due to the indoor climate and to the heat losses from the building. Modern windows are designed with two or three panes in order to improve their thermal performance. The cavities between the panes are often hermetically sealed and filled with a gas with low thermal conductivity. A numerical study has been undertaken of the natural convection within the cavity, which plays an important role in the thermal performance of the window. Thermal radiation transfer will certainly play a major role in the heat transfer process; however, the focus here will be on the convective heat transfer.

The numerical calculations are performed on a model with two vertical parallel panes with constant surface temperatures. The cavity between the vertical panes is enclosed with insulated plates at the top and at the bottom of the model. The model is two-dimensional and the flow is assumed to be steady, laminar and incompressible. The governing equations for conservation of mass, momentum and energy are solved by the finite element code FIDAP.

The numerical results in the present study have been validated with the measurement results presented earlier by Elsherbiny [1]. Flow patterns, velocity and temperature profiles within the cavity are presented. The variation of the Nusselt number along the height of the hot pane as a function of the Rayleigh number is also investigated.

Correlation for the average Nusselt number, Nu, as a function of aspect ratio, *A*, and the Rayleigh number, *Ra*, are determined. The correlation covers the range of values for, *A*, and, *Ra*, which are of practical interest in window construction. Based on regression analysis, the following correlation is proposed, $Nu = 1+ 0.00137\, A^{-1.137}\, Ra$. In addition, for further validating of the present study, the predicted results are compared with the results obtained theoretically and numerically by others.

Keywords
Well-insulated windows, Heat transfer, Natural convection, Numerical analysis, Enclosed cavity

Introduction

In Sweden and the other Nordic countries the climate is cold several months a year. To a great part the indoor climate of a building depends on the outdoor temperature and the quality of the insulation affects heat transfer in the building, i.e. the components of the building shield. The windows are an important building component for the indoor climate, but there is a down-draught problem, as the temperature is lower on the glass than the indoor air. For the last 50 years, the construction of the windows has developed from single-glazed constructions to today's triple-glazed constructions, with enclosed spaces between the panes, see Moshfegh et al [2]. Examples of gases, usually used in these enclosed spaces, are air, argon, krypton, xenon, CO_2 and SF_6.

Natural convection in vertical and inclined spaces has been investigated both analytically and experimentally for the last 40 years. The first important theoretical analysis was done by Batchelor [3] in 1954, after that many more studies have been carried out. Over the years, the studies have focused different circumstances such as limited Rayleigh numbers, *Ra*, and aspect ratios, *A*. In 1980 Elsherbiny [1] investigated a large scale of Rayleigh numbers and aspect ratios. As computer capacity has improved during the last decade, the possibility to solve the problems numerically has increased considerably. In 1995 H. Schweiger et al [4] made numerical simulations on laminar natural convection in rectangular cavities for different Rayleigh numbers at $A = 40$.

The purpose of this paper is to analyse numerically the convection between two vertical parallel plates forming an enclosed cavity. The region, which is of interest in this paper, is window constructions with Rayleigh numbers up to 20000 and the aspect ratio from 40 to 130. This region normally covers window constructions with a space width of 10- 15 mm, a height from 400 to 1900 mm and with common gases inside the cavity such as air and argon, with outside temperatures normal for Nordic countries in the wintertime.

The numerical calculations will solve the governing equations for conservation of mass, momentum and energy. The actual model is two-dimensional and the flow is steady, laminar and incompressible. The physical model, which the governing equations will be solved on, is a rectangular cavity with an isolated top and bottom and with two vertical plates of different temperatures. The governing equations are solved by the finite element method. The results from the numerical calculations are validated with results from other investigators. The intention with these numerical calculations is to find a correlation where the Nusselt number depends on both the Rayleigh number and the aspect ratio.

Physical model

The numerical calculation is made on a model, very close to reality (see figure 1). *H* is the height of the model, constantly 640 mm. *L* varying from 4.9 mm to 32 mm and is the width of the enclosed cavity between the two vertical panes. Heat transfer between two panes of different surface temperatures in an enclosed space can be performed with the three mechanisms conduction, convection and radiation. Convection and conduction are the two mechanisms considered in this paper. The radiative heat transfer is not negligible but it is not taken into account in the present study. The physical model is intended to be an enclosed space in a window construction therefore the Rayleigh number, *Ra,* and the aspect ratio, *A*, are limited to values which are of interest for window application. Air, argon, krypton, xenon, SF_6 and CO_2 are conceivable gases to use within the cavity in window constructions. The Rayleigh number and aspect ratio of interest is up to 20000 respectively 40-130.

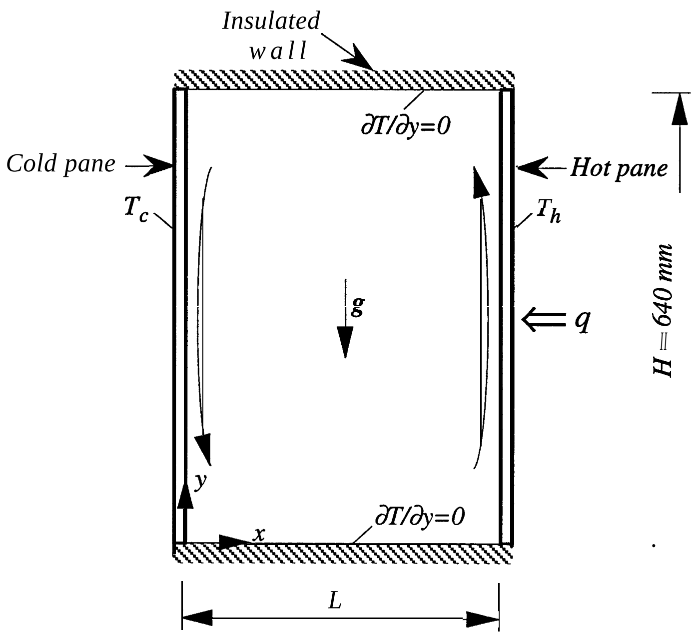


Figure 1. The physical model under consideration

Numerical calculation

The flow inside the enclosed space is assumed to be steady, laminar, incompressible and two-dimensional. Viscous dissipation is neglected and all thermo-physical properties of the fluid in the enclosed space are assumed to be constant, except for the buoyancy term of the y-momentum equation, i.e the Boussinesq approximation, see Gray et al [5]. There are no radiative processes between the surfaces. Considering the above mentioned assumptions the following governing equations are obtained.

Equation of the conservation of mass

$$\partial u/\partial x + \partial v/\partial y = 0 \tag{1}$$

Equation of the conservation of the momentum

$$\rho(u\partial u/\partial x + v\partial u/\partial y) = -\partial p/\partial x + \mu(\partial^2 u/\partial x^2 + \partial^2 u/\partial y^2) \tag{2}$$

$$\rho(u\partial v/\partial x + v\partial v/\partial y) = -\partial p/\partial y + \mu(\partial^2 v/\partial x^2 + \partial^2 v/\partial y^2) + \rho g\beta(T - T_{ref}) \tag{3}$$

Equation of the conservation of energy

$$\rho c_p(u\partial T/\partial x + v\partial T/\partial y) = k(\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2) \tag{4}$$

For faster convergence of the numerical solution the governing equations are solved in a dimensionless form. These following dimensionless parameters are introduced.

$$x^* = x/L, y^* = y/L, \ T^* = (T - T_{ref})/(T_h - T_c), p^* = p/p_{ref}, u^* = u/u_{ref}, v^* = v/u_{ref}$$

Where $T_{ref} = T_c, u_{ref} = \alpha/L, p_{ref} = \mu\, u_{ref}/L$. By using the proposed parameters, the dimensionless governing equations are derived as:

Conservation of mass

$$\partial u^*/\partial x^* + \partial v^*/\partial y^* = 0 \tag{5}$$

Conservation of momentum

$$1/Pr(u^*\partial u^*/\partial x^* + v^*\partial u^*/\partial y^*) = -\partial p^*/\partial x^* + \partial^2 u^*/\partial x^{*2} + \partial^2 u^*/\partial y^{*2} \tag{6}$$
$$1/Pr(u^*\partial v^*/\partial x^* + v^*\partial v^*/\partial y^*) = -\partial p^*/\partial y^* + \partial^2 v^*/\partial x^{*2} + \partial^2 v^*/\partial y^{*2} + Ra\, T^* \tag{7}$$

Conservation of energy

$$u^*\partial T^*/\partial x^* + v^*\partial T^*/\partial y^* = \partial^2 T^*/\partial x^{*2} + \partial^2 T^*/\partial y^{*2} \tag{8}$$

By comparing the governing equations with the dimensionless form of the governing equations these relationships are obtained

$$\rho = 1/Pr, c_p = Pr, \ \beta = Ra\, Pr, \ k = 1, \ g = 1, \ \mu = 1$$

Where

$$Ra = \beta\, g\, (T_h - T_c)\, L^3/k\, \alpha\, \upsilon, \ Pr = \upsilon/\alpha \tag{9}$$

Boundary condition in dimensionless form

On the hot pane	$u^* = v^* = 0, T^* = 1$
On the cold pane	$u^* = v^* = 0, T^* = 0$
On the insulated walls	$u^* = v^* = 0, \partial T^*/\partial y^* = 0$

The finite element code FIDAP, is used to solve the governing equations, see [6]. Non-uniform grids are used in such a way that grids points are placed at geometrically decreasing distances in the regions next to the walls, where large gradients of velocity and thermal gradients are expected. Grid refinement is applied to check the accuracy of the solution. A number of grid systems, eg. 20×100, 30×100 and 40×200 are considered and the grid system of 30×100 nodes is used for the solutions presented here for aspect ratio 40, as a trade-off between accuracy and efficiency. The demand for convergence of the solutions of temperature, pressure and velocity is when the difference between the iterations is less than 10^{-3}.

Numerical results

The results presented here are interesting for window constructions. Attention is focused on the effect of the Rayleigh number, *Ra,* based on the width of the cavity and aspect ratio of the cavity, *A,* and on the thermal behaviour of the gases within the cavity. The numerical results presented here are obtained for Rayleigh numbers, *Ra,* up to 20000, and aspect ratios, *A,* varying from 40 to 130.

The figure below shows results from a numerically calculated case where the Rayleigh number is 12000 and the aspect ratio is 20. The results, which are presented here, are the isotherms and the streamlines in the cavity; also the velocity at the top of the model are presented, see figure 2.

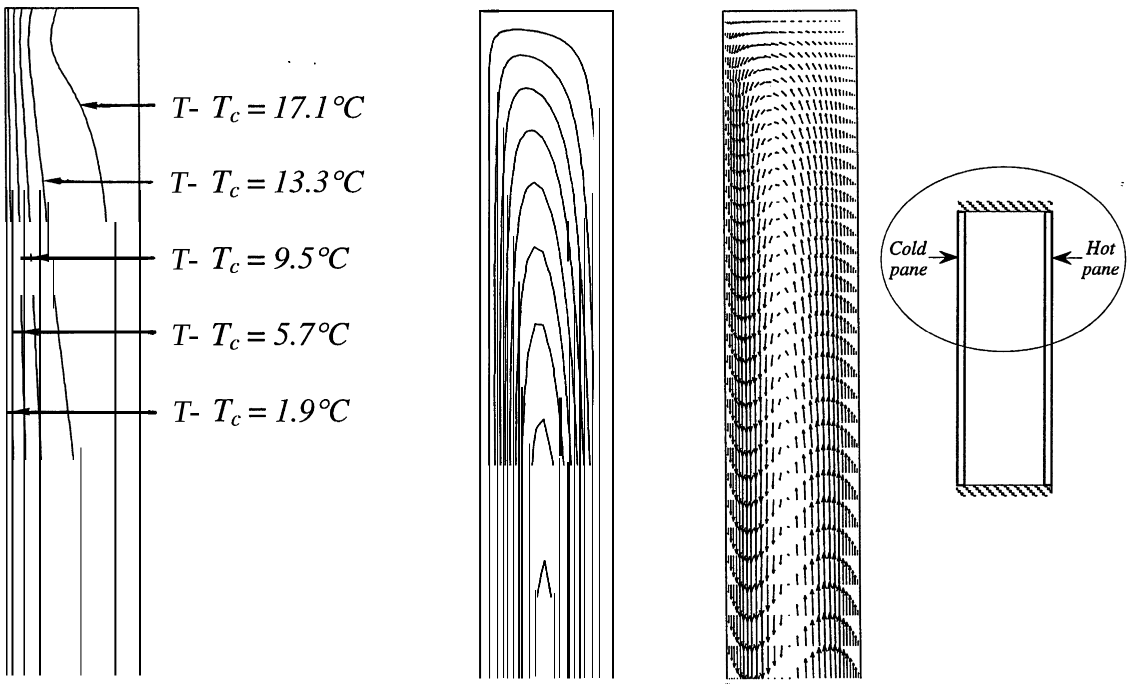


Figure 2. The predicted isotherms, streamlines and velocity for case Ra=12000 and A=20

To ensure the results from the numerical simulations of the model are reliable the results have been validated (see table 1) with measurements from Elsherbiny [1]. In addition, the predicted results are compared with the results obtained theoretically by Batchelor [3] and numerically by Schweiger et al [4] for aspect ratio 40 only, for further validation of the present numerical simulation. When Elsherbiny made his measurements he regulated the Rayleigh number,. *Ra*, by changing the density, p, with different pressure inside the enclosed space. Only calculations for atmosphere pressure were considered in the present study for numerical simulations. Therefore only measured values for aspect ratios, *A*, up to *A* = 40 were used, for higher aspect ratios in atmospheric pressure Nu = 1 which means that there is no convection in the enclosed space.

The mean Nusselt number over the whole height of the cavity is obtained by

$$Nu = \frac{1}{k \cdot \left(H/L\right) \cdot (T_h - T_c)} \int_0^H q \cdot dy \qquad (10)$$

Case	*A*	*Ra*	Nusselt number, *Nu*			
			ref.[1]	ref.[3]	ref. [4]	present study
1	5	2610600	8.374	12.637*	-	8.279
2	10	343250	4.417	6.399*	-	4.367
3	20	37970	2.200	3.103*	-	2.063
4	40	5765	1.062	1.200	1.100	1.083
5	80	4000	-	1.070	-	1.038
6	120	4000	-	1.046	-	1.019

* *Pr = 0.7*

Table 1. Validation of the Nusselt number, Nu

When there is only one flow in the enclosed space, which means there is no secondary flow in the space, the Nusselt number is constant except at the top and at the bottom where the flow turns. In this regime, there is only conducting heat transfer and it is therefore called the conduction regime. The next regime is called the boundary layer regime and in this regime the heat transfer endures through the enclosed space both conducting and convection. Here the Nusselt number is not constant all over the enclosed space. The local Nusselt number decreases along the hot pane and because of that the Nusselt number must be measured all over the space. Elsherbiny measured the average Nusselt number over three areas and these three average numbers form a total average number for the whole space..

The Nusselt numbers along the height of the hot pane as a function of, *Ra*, for *A = 40* are shown in figure 3. The graph shows the numerically predicted local Nusselt numbers and the triangle stands for the measured average Nusselt numbers over the three areas. One reason for the difference between the measured and the simulated results for *Ra* = 5765 was that the value was measured over an area and then an average Nusselt number has been calculated over this area.

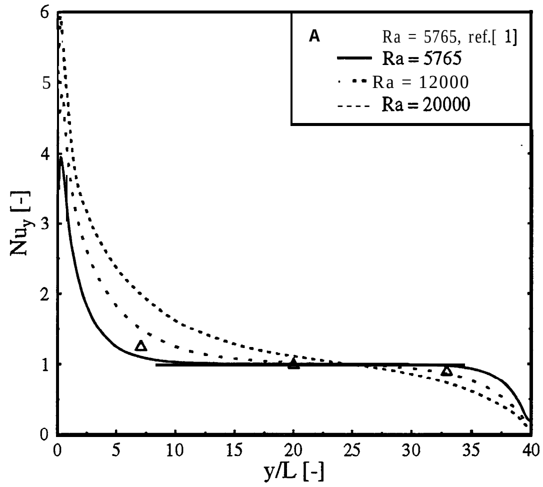
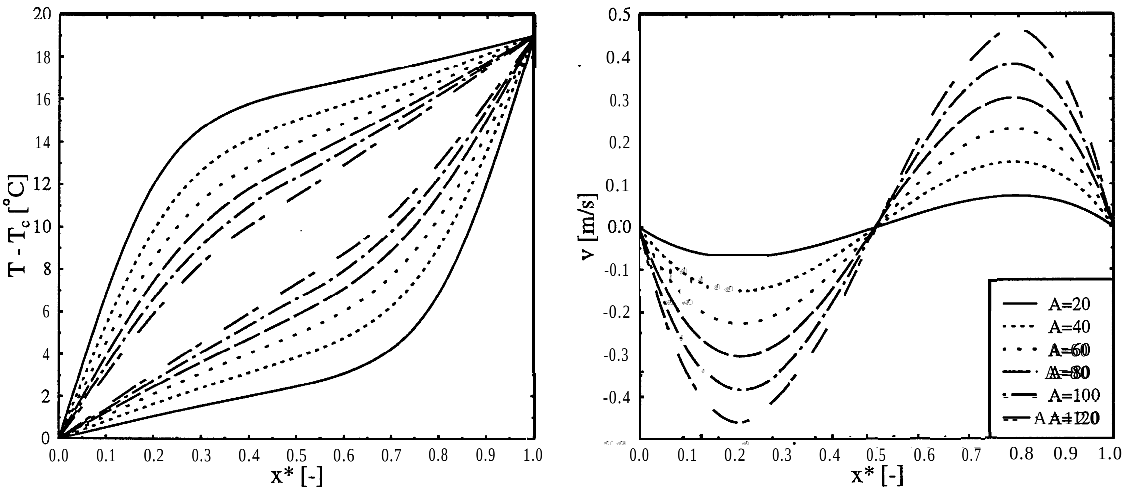


Figure 3. The local Nusselt number along the height of the heated wall

If the Rayleigh number, *Ra,* is constant and the aspect ratio varies, convection heat transfer will change within the enclosed space. When the aspect ratio decreases (the width of the enclosed space increases) the convective heat transfer increases.

Figure 4a presents temperature gradients at heights y = 30.5 mm and y = 609.5 mm. The Rayleigh number, *Ra,* is 12000. The figure shows that when the aspect ratio decreases from *A* = 120 to *A* = 20 the temperature gradient declines gradually, which shows that convection rises with the space width. The figure also shows that the temperature gradient is inversely symmetric at the two heights.

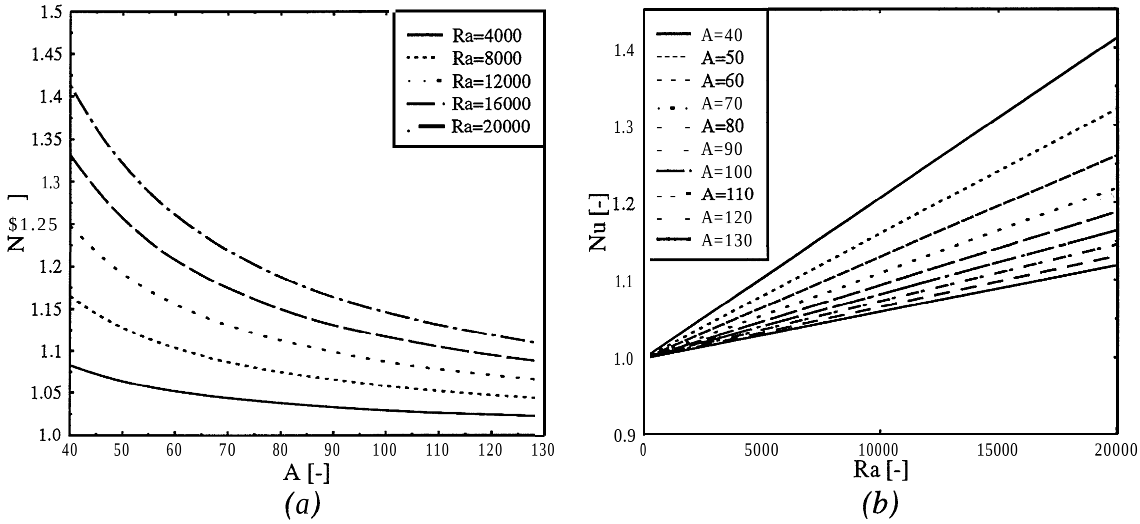


0 *a* (*b*)

Figure 4. Temperature gradient at y = 30.5 mm, y = 609.5 mm (figure 4a) and velocity profile at y = 320 mm (figure 4b) for different aspect ratios.

Figure 4b shows that when the aspect ratio, *A*, increases, the velocity, v, in the enclosed space will also increase. On the side where x^* = 1 (the hot pane) the gas rises while on the side where $x^* = 0$ (the cold pane) it falls. The velocity curves are inversely symmetric at $y^* = 0.5$. The figure 4b shows the velocity in the middle of the height (y = H/2) at a Rayleigh number of about 12000.

Figure 5 shows that there is a dependence between the Nusselt number, *Nu*, and the aspect ratio, *A*, the dependence of the Rayleigh number on the Nusselt number, Nu, is showed in the figure. Figure 5a presents the Nusselt numbers for aspect ratios from *A* = 20 to *A* = 120 at Ravleigh numbers up to *Ra* = 20000. Figure 5b displays the same results as figure 5a bu. the graph is made for Nusselt numbers against Rayleigh numbers.



Figures 5. Variation of the Nusselt number as a function of the aspect ratio (figure 5a) and Rayleigh number (figure 5b).

The main goal of the present study is to obtain a correlation for the rate of heat transfer, Nu, as a function of *Ra* and *A*, over the range of values that are of practical interest in window applications. According to figure 5b the best-fitted expression, which represents the numerical results, has the following form:

$$Nu = 1 + C_1 \cdot A^{C_2} \cdot Ra^{C_3} \quad (11)$$

Where C_1, C_2 and C_3 are 0.00137, -1.137 and 1 .OOO respectively. The coefficients are in good agreement with those proposed by Batchelor [3].

Case	C_1	C_2	C_3	Limitations
Present study	0.00137	-1.137	1 .000	$40 \le A \le 130,\ 0 \le Ra \le 20000$
Batchelor [3]	0.00 139	-1.000	1 .000	$A > Ra/500$

Table 2. Coefficients to equation 11

The gases suitable for window constructions have a Prandtl number, *Pr,* which varies from 0.6 to 0.8. Numerical calculations for *Pr* from 0.5 to 1.0 have been performed with constant Rayleigh numbers and the results from these calculations indicate differences smaller than 1%, which means that the Nusselt number is independent of *Pr,* when the Rayleigh number is specified.

Conclusions

An investigation was made to provide better understanding of the mechanism of convection heat transfer in a rectangular enclosure by means of numerical method. The analysis covers the range of values for aspect ratio, *A,* and the Rayleigh number, *Ra,* which are of practical interest in window construction.

For laminar natural convection within the cavity, the Nusselt number, *Nu*, according to the numerical predictions presented here is proportional to the, A^{C_2}, and Ra^{C_3} where C_2 is -1.137 and C_3 is 1 .O, respectively, for the interval $40 \leq A \leq 130$ and *Ra* up to 20000. The proposed correlation for, Nu, is unique because it covers the geometry and fluid properties as well as boundary conditions which are relevant for thermal analysis of window construction.

The predicted results are in good agreement with the results obtained theoretically and experimentally as well as numerically by other researchers.

Acknowledgement

The authors will thank Elitfönster AB, (Lenhovda, Sweden), Överum fönster AB, (Överum, Sweden), Pilkington AB (Halmstad, Sweden) and the Ministry of Education, (Stockholm, Sweden) for their financial support.

References

1. Elsherbiny, S. M. *"Heat Transfer by Natural Convection Across Vertical and Inclined Air Layers"* University of Waterloo, Ontario, Canada, 1980.
2. B. Moshfegh, D. Loyd and B. Karlsson, *"Heat Transfer at Modern Windows – Risk of Condensation"* Energy and Building,
3. Batchelor, G. K. *"Heat Transfer by Free Convection Across a Closed Cavity Between Vertical Boundaries at Different Temperatures"* Quarterly of Applied Mathematics, vol. 12, No. 3, pp.209-233, October 1954.
4. H. Schweiger, A. Oliva, M. Costa, C. D. Perez Segarra and A. Ivancic, *"Vertical Experiments on Laminar Natural Convection in Rectangular Cavities with and without Honeycomb-Structures"* Int. J. Numerical Methods for Heat and Fluid Flow, vol. 5, No. 5, July 1995.
5. D. D. Gray and A. Giorgini, *"The validity **of** the Boussinesq Approximation **for** Liquids and Gases",* International Journal of Heat and Mass Transfer 19, pp. 545-*55* 1, 1976.
6. Fluid Dynamic International. 1995. Evanston, IL, FIDAP version 7.5 1.

Thermotropic layers to provide shading for outside walls

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Abstract
In modern architecture glazing structures for walls, roofs, green houses or malls are common. To avoid moisture condensation and heat losses in winter periods, they have to use Low-E glasses with shading devices to prevent an overheating in the summer. Such shadings with blinds inside or outside are expensive to construct, to work and to. serve. An alternative system is under consideration of all these criterions, with the method of Quality Function Development (QFD), patented: a glazing with a thin layer of a thermooptical polymer as adaptive shading (TOPAS). Such a system is transparent in winter for a higher solar energy gain and opaque in summer periods to reduce the energy transmission. The switching temperature can be influenced and therefore calculated for different use in orientation, locality of the building and favourite climatic conditions inside for human comfort. Prototypes of such thermotropic glazings are in analysis and in production.

Keywords:
adaptive shading, overheating, solar protection system, thermotropic glazing, TOPAS

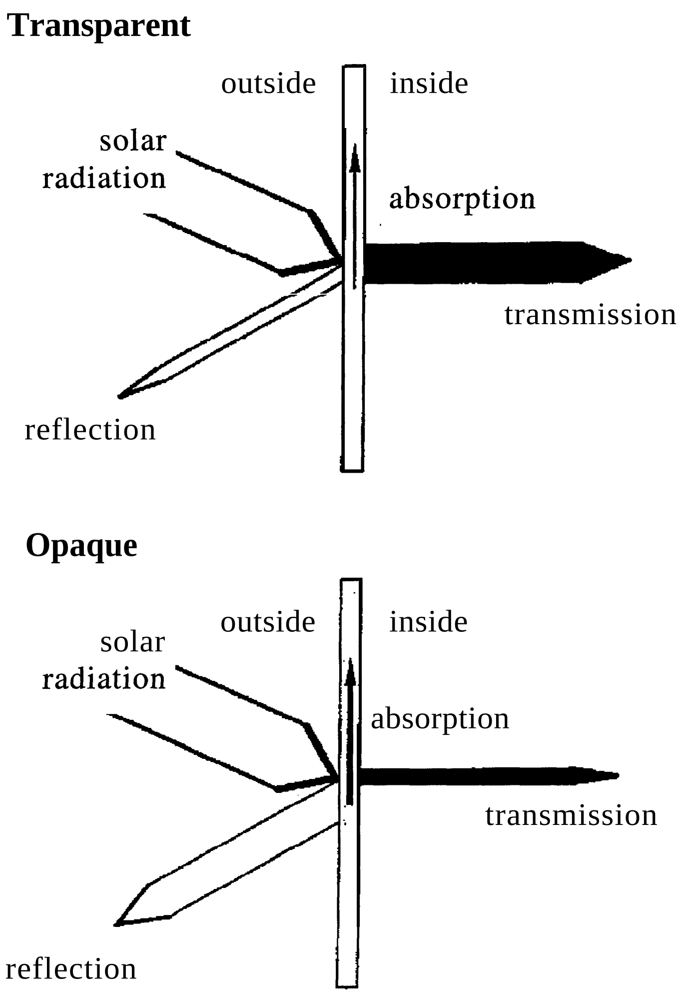
1. Introduction

Taking today's energy costs into account, the utilization of the potential building-heating savings offered by the employment of passive solar energy via transparent building materials in outside walls is extremely restricted. The economical usefulness of this "additional heating source" is decisively influenced by the solar protection system employed. Traditional "mechanical" solar protection devices such as roller-blinds, awnings etc., which are used to prevent the overheating of interiors in summer, are cost-intensive because of their complicated construction, control, regulation and maintenance requirements. In many cases, such systems can only be employed to a limited degree, e.g. when shading overhead glazing or large areas of translucent roofing.

A simple thermotropic shading system in the form of a pure polymer layer in the glazing or the transparent façades could eliminate the cost disadvantage.

The reversible shading mechanism of thermotropic layers is based on the reduction of transmission as temperatures rise. When the temperature of the outside air is low, solar energy can penetrate the transparent layer. But when the temperature of the outside air is high, e.g. during the bright summer months, a large proportion of the solar radiation is reflected by the layer. Fig. 1 is a schematic representation of radiation penetration in the case of such a thermotropic system.

Fig. 1
Schematic representation of radiation penetration through a thermotropic system



Materials consisting of a mixture of polyether and water, encased by an aqueous layer of vinyl carboxyl gel and applied to the interior of the double glazing, have been known since 1985 [1] and developed by the Fraunhofer Institute for Building Physics. Problems connected with the sealing of the edges and the application techniques led to new considerations involving the replacement of the aqueous gel system by an easy-to-apply, thermotropic polymer layer system.

2. Materials approach

The opacity mechanism is based on the existence of two phases above a defined opacity-production temperature with differing optical density. It has already been pointed out in scientific publications that partially mixable systems may exercise a thermotropic function. Partially mi.xable systems have a thermodynamically metastable range which may be utilized as a thermotropic opacity-production mechanism. These metastable systems, however, generally exhibit a high opacity-production temperature [2].

Investigations showed that the phase separation of completely segregating systems can also be used to generate thermotropic opacity [3]. These systems are characterized by the fact that the generation of opacity is not attributable to any chemical connection between the two phases. The effect is, rather achieved via the differing temperature dependence of the refractive index of the two phases, which are always present separately. Primarily, preference is to be given to globule-segregated systems containing a component which, due to a change in modification or conversion of phase, exhibits a strong discontinuity in the course of the refractive index, dependent on temperature.

Since the molecular vibrations of a substance increase as the temperature rises, its optical density diminishes and the refractive index falls. If a change in phase or modification occurs during a change in temperature, this can be mirrored by a strong change in optical density. If a Substance A is mixed with a Substance B exhibiting such a change in structure, a difference in refractive index may occur leading to a diffusion of the incoming radiation. The number, size and geometry of the diffusion centres B and of the difference in the refractive index are the parameters which determine the reflection and transmission properties of the mixture of substances.

Various alcohols, ketones, esters, aromatic and aliphatic compounds as well as carbonic acids exhibit a change in modification or phase within the above-mentioned temperature interval. Fig. 2 shows the refractive index n_D in dependence on the temperature for a few selected monomers. As the course of the graph for the aromatic compound clearly shows, a phase transformation does not inevitably lead to a stepwise course of the measured line, as this is essentially dependent on the structure which forms. Both the selected carbonic acids and the aliphatic compounds are characterized by a clear, structure-dependent modification of the optical density. The aliphatic compound shown in Fig. 2 exhibits the greatest difference in refractive index at phase transformation of all monomers investigated, and should thus be suitable as a thermotropic component.

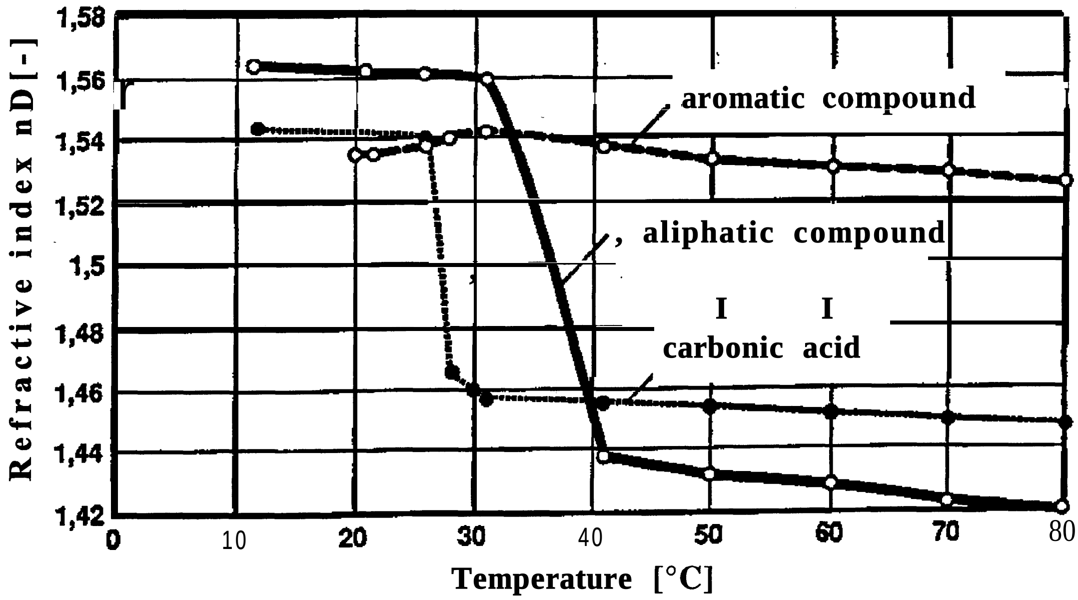


Fig. 2 Refractive index of selected organic monomers in dependence on temperature

By selecting a corresponding class of polymer, the refractive index n_D^{20} of the matrix polymer can be adjusted within a range of 1.48 to 1.60. The use of PES matrix systems is recommending in combination with this aliphatic compound.

3. Production

Starting with the aliphatic compound and a UV-curable polyester, a solution is formulated with the help of a reactive solvent. The easy flowing solution can be poured into to the interior of a double glazing, consisting of a cheap selfadhesive spacer as temporary sealant, using established application techniques. In the next step a quick UV-curing process takes place initiated by a short UV-exposure. Thermotropic layers approx. lmm thick are produced.

When the layer is being formed, the curing conditions determined by time, temperature and intensity of the radiation exercise a strong influence on the radiation-related properties of the thermotropic layers. This is determined by the size of the crystals of aliphatic compound forming within the layer, their distribution within the matrix structure and the possibility of nucleation as re-crystallization of the liquid monomer globules begins after their temperature drops below precipitation level. Fig. 3 shows a photograph of two glass sheets laminated with a 1 mm thick thermotropic layer, the left-hand half of which has become opaque after exposure to a current of hot air of approx. 40°C.

Fig. 3 Photograph of a thermotropic glazing consiting of two glass sheets with a 1mm thick thermotropic TOPAS-layer. (Geometry of sample approx. 700 x 700 mm)

4. Properties

The opacity produced by the change in modification in the case of the thermotropic layer developed can be quantified on the basis of the rectified-hemispherical transmission. Fig. 4 shows the rectified-hemispherical transmission in the wavelength range-from 380 nm to 2250 nm for a layer at two different temperatures. The degree of light transmission is lowered by the reduction of transmission from 0.86 to 0.43.

The degree of radiation transmission is reduced from 0.84 to 0.55. As the measured lines show, no distinct bands of absorption occur in the wavelength range of global radiation. Accordingly, these layers are purely reflecting systems which can be expected to exhibit corresponding values in their overall degree of energy permeability. These investigations are at present being prepared, utilizing a newly developed calorimetric g-value testbed.

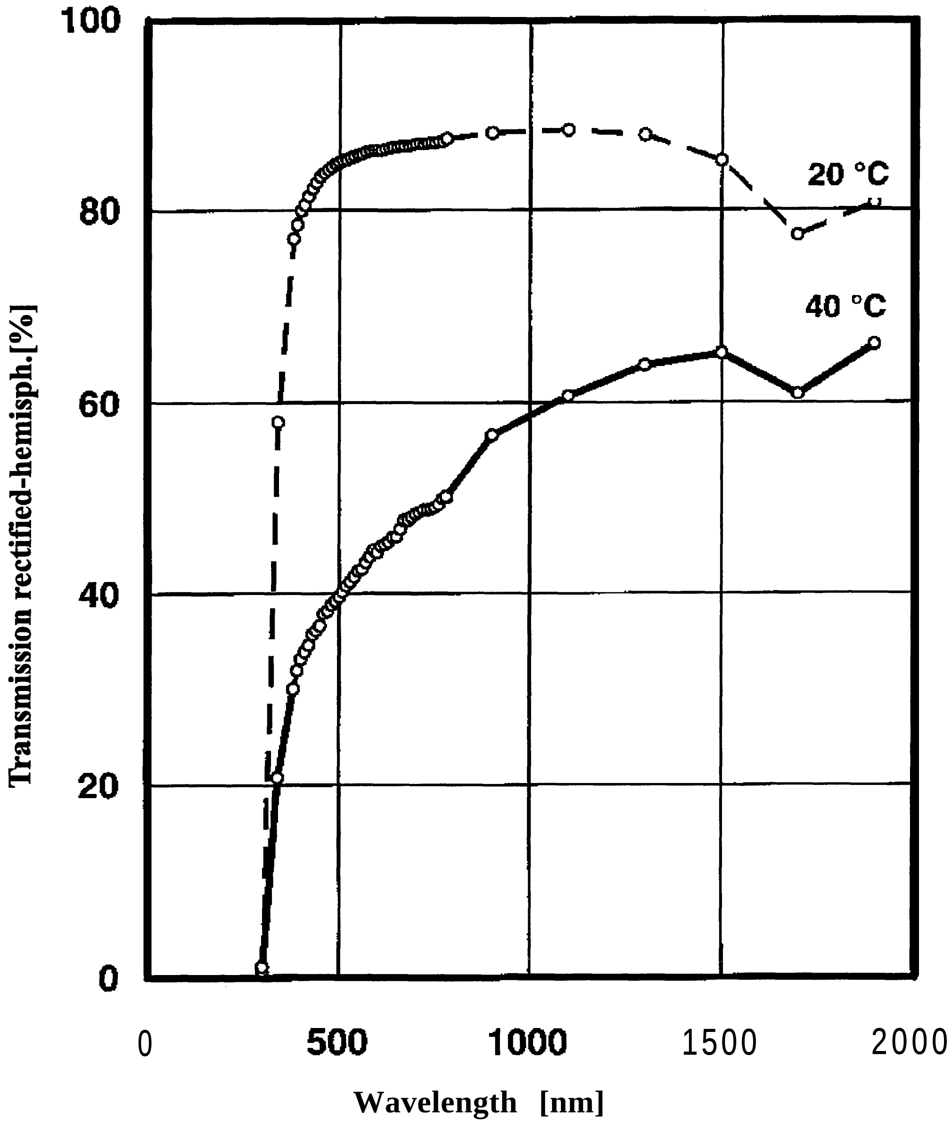


Fig. 4 Rectified-hemispherical transmission of a thermotropic coating at temperatures below and above the opacity-formation temperature.

Boundary conditions:
Layer thickness approx. 1 mm
Oacity-formation temperature 35°C

As ageing investigations show, the embedding of the thermotropic components in the polymer matrix plays a decisive role in resistance to ageing. In order to exclude the influence of any ageing processes and to further develop the product into a industrially usable commodity, a combined project with glass and coatings manufacturers, also including the paint-chemicals industry, has been initiated.

5. Bibliography

[1] Meinhardt, S. et alii: Temperaturabhangige Lichtdurchlassigkeit von Gläsern (TALD) (Temperature-dependent Light-permeability of Various Types of Glass). Report SA 1/85 of the Fraunhofer Institute for Building Physics, Stuttgart (1985).

[2] Paul, D. R.; Barlow, J.: Polymer Blends. Journal of Macromolecular Science - Review of Macromolecular Chemistry (1980), C 18, pp 109-168.

[3] Gödeke, H.: Thermotrope Außenwandbeschichtungen. (Thermotropic Coatings for Outside Walls). Concluding report of DFG Project Ge 368/15- 1, Report GB 129/1995 of the Fraunhofer Institute for Building Physics, Stuttgart (1995).

Assessment of a hybride heating system with ventilated concrete ceiling

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Abstract
To reduce the energy consumption in buildings we developed a heating system with a solar air collector and ventilated concrete slabs in the ceiling, so this heavy building part is the heat storage on sunny days in the afternoon, and we can restore in the evening and night in nothern part of the building the solar gains. Such systems can also be used for summer cooling.
To restore the heat by air ventilation, the tubes in the ceiling are in contact with the room air, so we have to avoid dust and mould growing in the slab with filter systems and in advance by correct design calculations: for different constructions of dimensions, air conditions and insulation in the critical zones of the ceiling (near the collector- adapter) we calculated the risk using a fuzzy transfer function for the probability of mould growing. The calculated energy reduction in the winter period for the hybride system was about 10 to 25 %, compared with traditional fuel heating. In two winter periods the measurements in practice showed a reduction of 11,4 % with an efficiency ratio of hybride gains to solar radiation on the collectors of 15 %.
To get a rent of invest the system components must be simple enough or with double function like the ceiling slab: in the model case with the investigated small l-family house the additional costs for the whole hybride system were about 55000 DM or 4600 DM per m² installed collector area. Compared with the area specific heat consumption of 94 kWh/m²a and the hybride solar gains of about 1 MWh/a the hybride system is as a prototype working very well, but too expensive. But there is a greater potential for rationalization in multi- family houses and when the solar collectors are integrated in a facade system between the windows of the different floors.
The compatibility of new technology, energy reduction and thermal comfort could be measured in the experiments by air exchange rates in sunny winter and summer periods. The indoor air temperatures were in comfortable behaviour and supplemented by direct gains through windows in the afternoon and by the hybride system in the night.This investigation shows that the pre- calculation about modelling of the hybride system gave a sufficient prediction of indoor air temperatur and reduction in energy consumption, so we have some advices for further developments.

Keywords: energy consumption, hybride air heating system, mould risk, solar collector, system costs, thermal behaviour (IAQ), ventilated concrete slab.

1. Introduction

To reduce heat energy consumption in buildings the heating system shall be transfer quick enough the needed amount of heat to make each room comfortabel in temperature and air distribution. In high insulated buildings there are often problems of overheating in the seasons with great solar radiation as direct gain through windows and in the summer due to internal loads. Wall or ceiling elements can be made hollow to reduce the weight and to keep the static stability with air tubes in e.g. leightweight concrete slabs. In combination with an air heating systems, which is easy to regulate, we can ventilate the ceiling or floor element with warm air from a solar collector on the outside of the building in winter or with cool air from underground or northern parts of the building. Such combinations of building and technical equipment are named „Hybride systems" and investigated in IBP by modelling the insteady heat storage and laboratory experiments on different ventilated wall and ceiling components [1,2]. The validation of such a system was investigated to the problem of mould growing in the ventilated components with all the influences of condensation, dust, temperature and moisture content by a lot of laboratory tests and calculations using fuzzy transfer function to avoid or reduce the health risk [3]. Experiments in an one-family house in Zaberfeld nearby Stuttgart are running about a time period of 1,5 years: the results in the reduction of heat energy, thermal behaviour and cost relations are reported.

2. Building and hybride system

The building was installed in 1995 according the data of the optimization calculations e.g. for the ventilated tube diameter (100 mm) in the concrete ceiling (36 m^2 equivalent 6 m^3), the dimensions of six solar air collectors or the air velocity for charging and discharging modes, see Fig. 1. There is also a scheme of the ground-plan (82 m^2) and the air flow from collector on the south wall through the ceiling to north side and back in a closed circuit. Between two charge tubes is one discharge tube, which is an open circuit to the living area for active, ventilator supported mode. The eastern part of the building is built up as a passive storage ceiling without separate discharge ventilators. The complete data about the hybride components and the building are given in [4] and some important values are added in Tab. 2.
The house is occupied by 2 persons since 1995 and the measurement equipment recorded each hour all the relevant data of the additional electric heaters, the condition of collectors, ventilators, heat storage in the ceiling, the room temperatures and the weathering.

3. Experimental results

For the heating periods of November 1995 till May 1996 the monthly temperatures and solar radiation conditions on the outside of the test building are reported in Tab. 1 with the energy balance between gains and losses due to transmission through building parts and air ventilation. The heating consumption depends on the natural fluctuation of the climate and is standardized in [4] to european test reference year (TRY). The original electric heaters in each room installed as night block storage elements are too inert: the

gains due to the hybride system (3 %, Tab. 1) were reduced from an overheating in the rooms, so we changed the elements to electric direct heaters in summer 1996. Then the efficiency of the solar collector in combination with the ventilated storage ceiling could be higher in the total period to 6 % and in maximum to 11 % (Oct. 1996). The distribution of the different parts in the gains and losses are shown in Fig. 2 for both heating periods. It is evident, that only in the months with higher solar radiation (e.g. in march on 19 days at noon > 500 W/m²) the hybride system is working well and the ventilators are running. The area specific heating energy was calculated with 94 kWh/m²a not in the level of a german „Low energy house“, but lower than the allowed government requirement (3 years ago) of 100 kWh/m²a for an A/V-ratio (1,2 m^{-1}) of this building. The efficiency of the hybride ventilated ceiling in relation to the solar energy in the collector is about 15 % over the period 1996/7 and can be optimized because the rate of internal loads and the room air temperature (14 kWh/m² and 22 till 25 °C) were much higher with our people in the test house than the statistical average.
To reduce the consumption of energy for the 12 ventilators (2 at each collector in each charging tube) and the noise in the room we used an air velocity in the tubes of 1,8 or 0,8 m/s: then we can gain 12 or 7 kWh per day with a solar radiation of 4 kWh/m².
The charging of the ceiling with warm air from the collector started at a solar radiation of > 200 W/m² and got a maximum in collector temperature of 50 °C (march 1996; 0,8 m/s) and of 35 to 48 °C in the ceiling near the air entrance. The temperature in the nothern part of the ceiling (tube redirection) was at 23 °C and below under the wanted 26°C, when an active discharging of the concrete storage is regulated. This can be reached with the higher air velocity in the tubes, but the occupant don’t want this mode although the noise of the hybride ventilators is below 35 dB(A), which is acceptable.

4. Assessment, validation and economy

According to the calculations to condensation risk and mould growing [3], we found no such problems in the separeted air circuits for charge and discharge of heat. The collector temperatures in summer were in maximum at 80 °C without shading and had no problems. A relevant part (8 %) of the solar energy is transfered through the wall between the collector backside to the rooms and influenced the direct gains and therefore the room temperatures and is lacking in the hybride energy balance (time shifted). The temperature distribution in the heated ceiling was not homogen: differences between surface and air of 15 K in south and of 5 K in north area. This can be lowered when using different thicknesses of the installed insulation under the ceiling for an active discharging.
The installation costs for the hybride system were for this small house and the production as a prototype too high to reach an ecomomic rent of invest: Tab. 2 gives the specific costs and the sum of 55000 DM without a reduction in the conventional block storage heaters (caused by the restrictions of the power supplier to dimension the units according the DIN- standard). The costs for the period 1996/7 to use environmental energy were 20 DM for ventilators electric power to earn from the sun an equivalent of about 900 kWh electricity or 225 DM. This unfortunately is not in an economic range, so we have to opimize the system in changing the additional heaters to small, cheap units, modification of the insulation layers, integration of window air collectors instead of separate wall element collectors and use of the hybride heating

system in buildings with a great amount of industrial prefabricated components perhaps in multi- store constructions.

5. Conclusions

The measurements in an one- family house over two heating seasons and a summer period have shown a sufficient agreement between predicted calculated temperature and heat energy distribution in hybride building components and the total reduction in heat energy consumption to fulfil1 a good thermal behaviour. Some potential could be identified for a further development and a better rent of invest in multi- store houses. Then we expect for such a heating system with a short- term concrete storage between the floors to transport the too much solar energy from south to north rooms a good chance.

6. Acknowledgements

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7. References’

[1] Oswald D., Bertsch K., Warmetechnische Bauteiluntersuchungen für hybride Heizsysteme (Energy relevant research on building components for hybride heating systems, in german), CCI H. 11, 199 1.

[2] König N., Oswald D., Rath J., Sedlbauer K., Bauteilintegrierte Heiz- und Haustechnik fur künftige Baukonzepte (Hybride Heizsysteme)- Phase 2: Bauteilkonzepte, Bericht GB 113/1994, Fraunhofer Institut Bauphysik, Stuttgart, 1994.

[3] Oswald D., Sedlbauer K., König N., Analyse und Prognose der hygienischen Zustände und Wartungsnotwendigkeiten in Außenwänden mit offenen Luftkreislaufen bei hybriden Heizsystemen, Bericht GB 128/1 995, Fraunhofer Institut Bauphysik, Stuttgart, 1995.

[4] Oswald D., König N., Wichtler A., Bauteilintegrierte Heiz- und Haustechnik für zukünftige Baukonzepte- Projektstufe 3 / Umsetzung an EFH Zaberfeld, Bericht GB 141/1997, Fraunhofer Institut Bauphysik, Stuttgart, 1997.

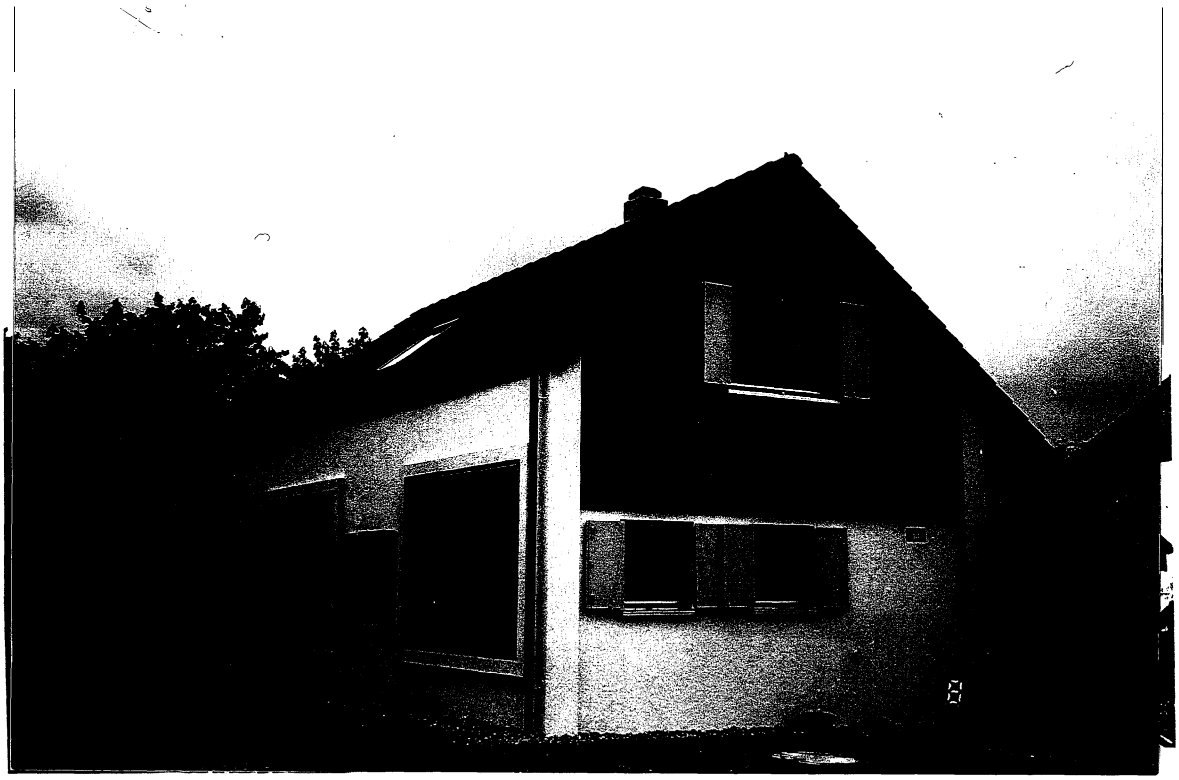
Tab. 1: Comparison of the monthly ratio of energy balance and the therefore important influences in the investigated building for the heating period 1995/96 and 1996/97.

Heating period		Temperature		Global solar radiation		Gains					Losses		Air change behaviour
		Outer air	Room air	South vertical	horizontal	Heating consumption	Internal loads	Windows	Hybride system	Collector Wall	Trans-mission	Ventilation	Ratio
		°C	°C	kWh/m²	kWh/m²	kWh	kWh	kWh	kWh	kWh	kWh	kWh	l/h
'95	November	3,9	22,3	46,4	32,9	1025	412	135	73	26	1337	334	0,3
	December	0,3	20,5	16,1	16,3	1278	480	70	15	20	1509	354	0,3
'96	Januar	-1,1	20,5	27,6	23,3	1391	454	96	28	20	1573	416	0,3
	Februar	0,0	21,6	50,0	45,2	1228	400	153	64	39	1474	410	0,3
	March	3,2	21,8	76,7	90,0	1093	466	339	124	41	1418	645	0,5
	Average Sum	1,3	21,3	43,4	41,5	6015 (64%) 1)	2212 (23%)	793 (8%)	304 (3%)	146 (2%)	7311 (77%)	2159 (23%)	0,34
'96	September	12,1	22,6	75,1	97,2	588	432	208	137	33	924	468	0,7
	October	10,5	24,4	64,0	58,5	924	393	177	193	17	1218	502	0,5
	November	6,1	23,2	31,0	25,9	1266	363	84	77	19	1347	460	0,4
	December	-1,2	20,8	36,2	21,9	1374	536	84	23	24	1648	388	0,3
'97	Januar	-2,6	21,2	29,6	15,5	1628	484	56	36	39	1763	465	0,3
	Februar	6,8	23,1	48,0	45,8	1029	370	167	82	24	1215	472	0,6
	March	8,3	22,8	67,9	80,1	875	419	279	184	35	1219	562	0,6
	April	8,8	22,3	95,0	135,6	524	435	373	156	28	1111	412	0,5
	May	14,4	22,8	83,7	169,9	316	455	478	88		842	523	1,0
	Average Sum	7,0	22,6	58,9 530,5	72,3 650,4	8524 (55%)	3887 (25%)	1906 (12%)	976 (6%)	246 (2%)	11287 (73%)	4252 (27%)	0,54

1) in relation to total sum.

Tab. 2: Compilation of the important parameters for the validation of the heating consumption and the solar gains in the hybride ventilated floor system of an one family building in the heating period 1996/97.

Parameter	Unit	Results
Heated living area	m^2	91
Area of wall air collector	m^2	12
Area of hybride ventilated ceiling	m^2	36
Heating energy consumption	kW h/a	8524
Area specific heating energy	kW h/m^2a	94
Hybride gains	kW h/a	976
Hybride gains / heating energy	%	11,4
Balance ratio of hybride gains	%	6,3
Efficiency (Hybride gain / solar energy collector)	%	15,3
Hybride gains / living area	kW h/m^2a	11
Ventilator energy	kW h/a	79
Hybride gains / ventilator energy	1/m^2	12,4
Costs of hybride system	DM	55190
Specific costs per m^2 collector area	DM/m^2	4600



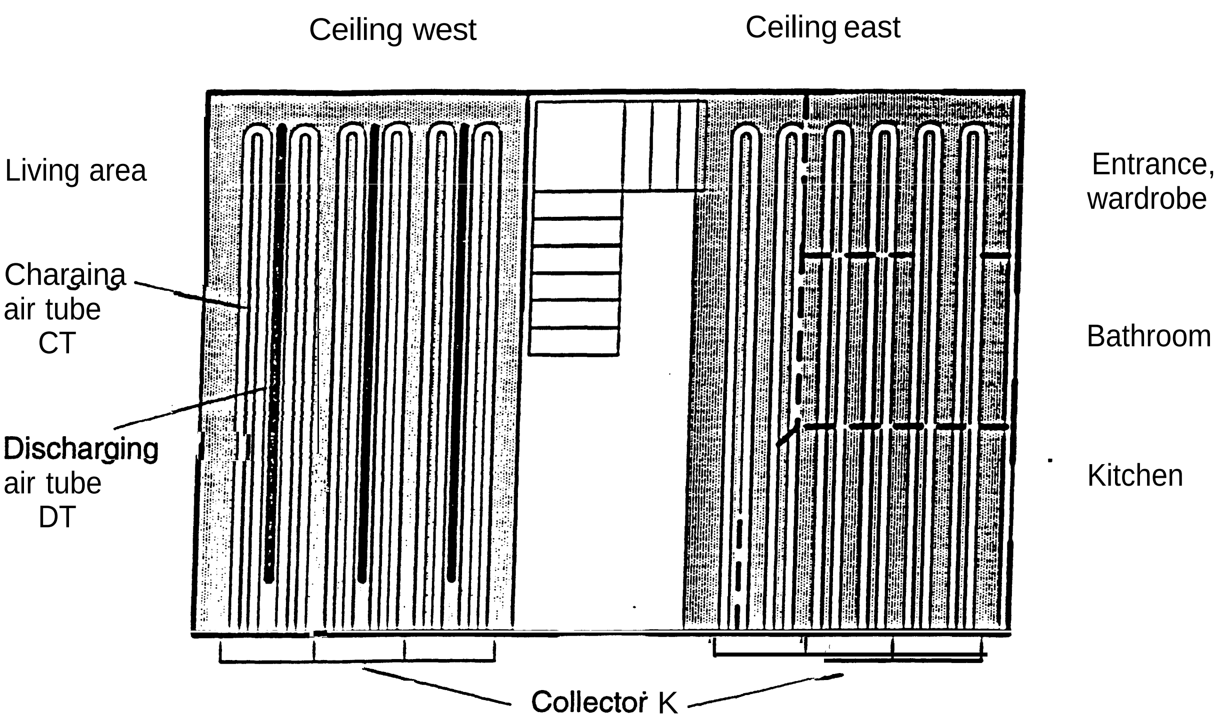


Fig. 1 : Photograph of the building with 6 air collectors on the south facade (above) and Cross section (below) through the hybride, ventilated ceiling system and scheme of the charging (CT) and discharging air tubes (DT) in the ceiling, 6 air collectors (K) on the outer wall and attachment of the rooms .

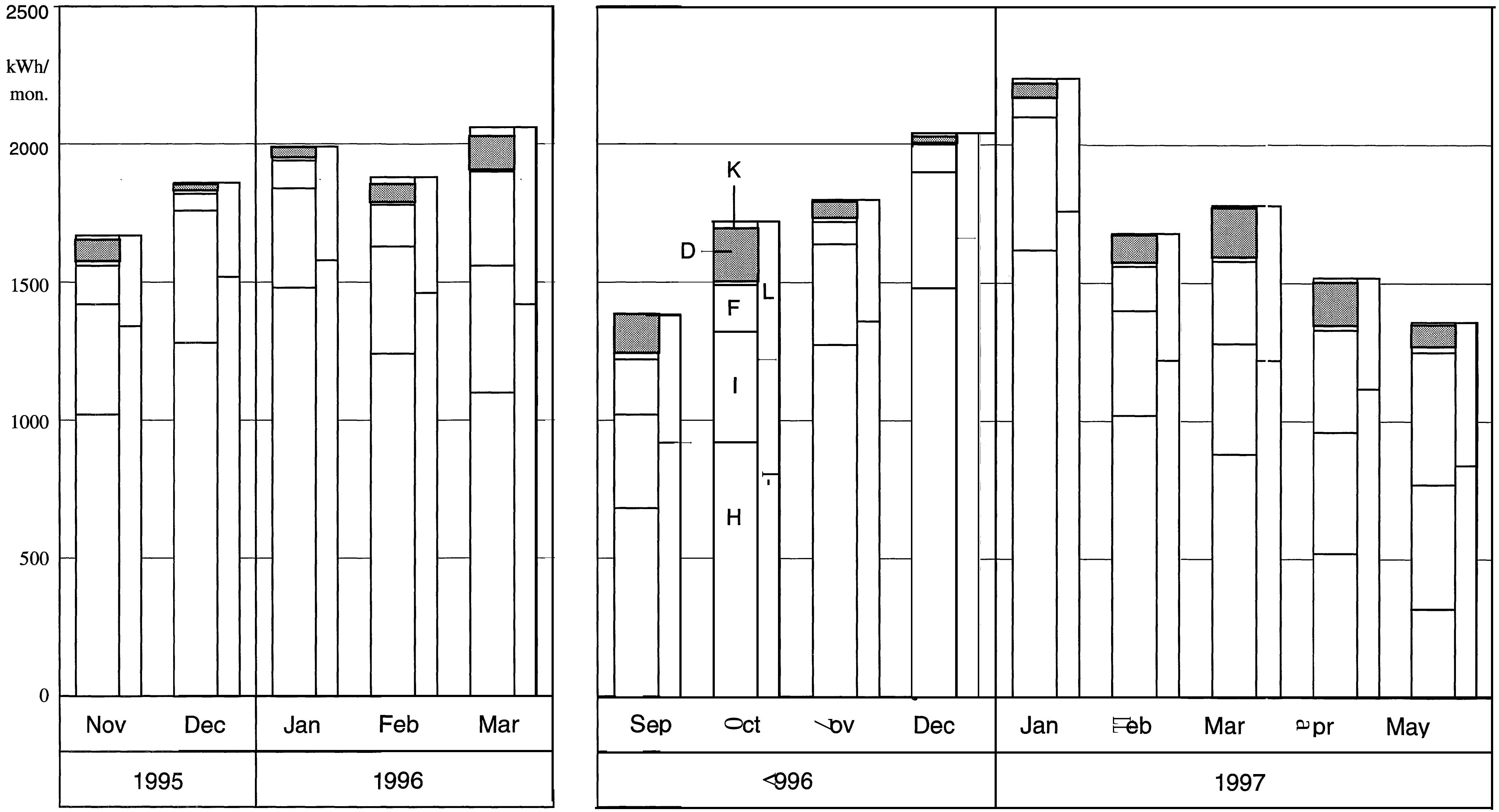


Fig. 2 : Ratio of energy balance per month for a house with hybride heating system in the measured period of november 1995 till may 1997

Gains : H = Heating system ; I = Internal Gains ; F = Windows ; D = Hybride ventilated Floor system ; K = Outer Wall behind Collector
Losses : T = Transmission ; L = Ventilation .

Value of indoor air quality to productivity

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Abstract

Researchers and others in many parts of the world have become aware that the productivity is dependent on a good indoor environment. The expression Indoor Air Quality (IAQ) seems to be replaced with Indoor Environment Quality (IEQ).

In most buildings in the service industry wages and wage-related costs represent 8590% of the total costs per workstation, and the increase in value is completely dominating the total economy. Our most important challenge in planning new and refurbishing old buildings is to create an excellent environment for productivity as well as for comfort.

Today we have an extensive knowledge of the most important factors in the total environment. In Norway we call them the "Environment's 7 sisters", including thermal, atmospheric, acoustic, actinic, mechanical, psycososial and aestetic environment. Good results depend on willingness to use this knowledge and build up competance, which contains knowledge, insight, behaviour and attitude from all persons involved in the building process.

In the USA and in Norway there have been some studies since the late 1980s concerning productivity related to indoor air quality and the indoor environment [1, 2, 3]. The most comprehensive was carried out by Dorgan Associates, Inc., prepared for National Energy Management Institute in USA (NEMI):

"The conclusion of this study is that improving indoor air environment will provide a high return on investment through productivity gains, health savings and energy reductions.

This paper will describe the preparation of an environmental plan for a new project including the "clean building philosophy" (CBP), energy efficiency and building procedures and show that this is good strategy.

Keywords:clean building philosophy, environmental plan, indoor air quality, productivity, total costs.

1 Introduction

An important factor in today's building industry including rehabilitation of existing buildings, is the owner's attitude towards contractors and all building workers and towards the users of the building after occupation. If, before starting the design work, the owner has insight in total economy and decides that he or she wants a clean and tidy construction site with no accidents during the construction period and good indoor air quality for the users, it is highly probable that he or she will obtain a good result. But it is also essential that in-house qualifications can cope with external architects and consultants, chosen as professionals rather than friends. The building owner must behave professionally and have in mind the final result and the total economy per work station. Financial understanding is necessary, and it must be understood in full that annual costs are dominated by wages and wage-related costs. An excellent indoor air environment including air quality and climate requires the best consultancy, both from architects, civil, electrical and HVAC (heating, ventilating and air conditioning) engineers.

It is documented that a rise in productivity of approx. 0.6 % in office buildings may justify a rise in investments for the HVAC system of about 60 %, according to Haukenes [1]. Totally this means that a good strategy for healthy buildings start with the owner's philosophy concerning the new project.

2. Environmental plan

A part of the important attitude is preparation of an environmental plan. This might be a good strategy. The purpose of such a plan is basically to define the environmental objectives of the project, considering the working environment and the environments.

A principal objective is to create a standard for internal environmental quality, including the amount of the best possibly filtered outside air, choice of heat recovery system and building materials, equipment, furnishing, carpet quality etc. The main goal is to obtain the best internal environmental quality including indoor air quality, thermal, acoustic and lighting environment. Both the design of the mechanical environment and aesthetic factors are important parts of an environmental plan, also including work-stress and psychological factors of different kinds.

Pilot Study on Indoor Air Quality and Climate - a [1]NATO/CCMS project including USA/Canada and 14 countries in Europe - has given us comprehensive knowledge of the most important elements in an advanced environmental plan. To maximise internal air quality during a building's lifetime one must include a plan for cleaning procedures and maintenance to prevent a negative influence on the indoor air quality after occupancy. For example, contents of organic dust can cause asthma and allergy, and the maximum of efforts must be made during the environmental planning period to reduce such (and other) contaminations.

Consultancy has for decades been focused on low investment costs - and later in addition on energy consumption. After the oil embargo in the mid 1970s, several energy conservation efforts have had a negative impact on the indoor air quality. This very unfortunate situation is about to be changed because of better documentation about the health effect of an adverse indoor climate.

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[1]NATO/CCMS - NATO/Committee of the Challenges of Modern Society

3. The “clean building philosophy” (CBP)

Implementation of a building project which employs new or innovative techniques requires the total cooperation and participation of sub-contractors. Accordingly, great emphasis is placed on the education of contractors and the displacement of conventional attitudes and practices. Unless individual workers can be convinced of the basic value of following “clean” construction procedures, there is no possibility of achieving one of the principal objectives of the original environmental plan, which was made for Tranberg College in Gjoevik and the Lysaker Market in Oslo West, Norway.

In summary, it can be fairly stated that these projects, while conventional in many respects, were carried out with a sensitivity to environmental issues which is quite new in planning in Norway. The main goal was to create educational conditions that will give no objective reasons to complain about the indoor air quality and climate - or the indoor environment.

The following areas were identified as having a potential effect on air quality for people, especially for children and female office workers:

- Dust and particulate matter generated during construction/reconstruction
- The quality and design of air handling equipment
- Maintenance procedures
- Selection of interior building materials and furnishings
- Emissions from office equipment, e.g. copy machines and laser printers

4. Control of contaminants

In response to the foregoing, the following specific measures were implemented for control of dust and other particulates contamination during the construction phase of the projects:

- All interior concrete surfaces to be spray-painted to minimise concrete dust and the smell of cement
- All wall penetrations for duct-work, cable runs, etc. sealed to avoid cross-contamination of building areas by dust/particulates
- All carpeting sealed off with PE-coated paper until all dust-producing construction activities is completed
- All duct-work sealed prior to delivery and after installation until just before start-up
- Use of vaccum cleaner to systematically remove accumulating construction dust and debris - daily and weekly
- All mineral wool insulation materials isolated from any contact with ventilation air, according to Hedge et al. [4]

The standardised air handling units (AHU) (Fig. 1) have been designed and equipped with a number of innovative features to maximise air quality and worker comfort, i.e.:

- No recirculation of air is employed to allow for a continuous purging of the building interior with filtered outside air

- Cross-connections between inlet and outlet duct-work are not allowed so as to eliminate possible "feedback" of contaminated air
- Two-step filtration - in air inlet and after the fan in the AHU - and possibility for a third step - HEPA or adsorption filter

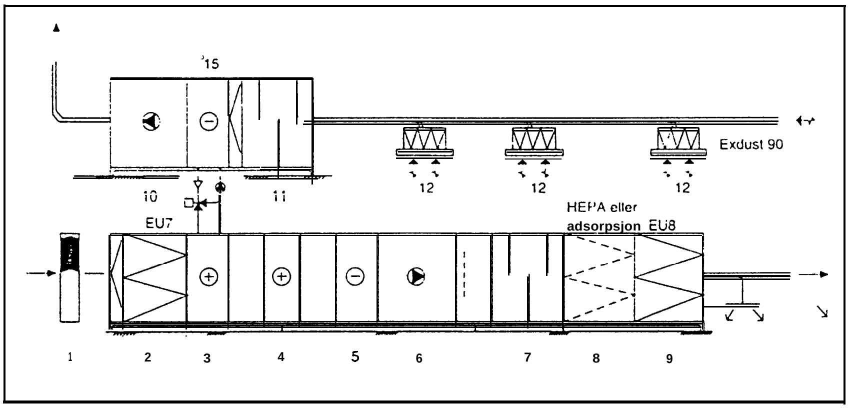

Figure 1. This figure shows an recommended AHU with EU-7 filter in air intake (2), water-glycol heat recovery unit (3/15), heating coil (4), cooling coil (5), supply fan (6), sound attanuator (7), possible adsorption filter (active charcoal) (8) and filter EU 8/9 before duct system. To maintain capacity in exhaust-system we strongly advise co-called exdust valves (12) or EU-7 filter before the sound attanuator (11).

While the build-up of dust and aerosols can be controlled in recirculating ventilation systems with properly designed filter systems, this is generally not true of fumes and gases. It is well known that some modern building materials and furnishings give off chemical fumes and vapours, some of which have been shown to be hazardous (e.g. formaldehyde fumes from wall panel insulation materials). While threats to health was not a major concern in this particular case, it was considered an important environmental factor to install a system which provides for continuous purging of the building interior with filtered, outside air, thereby minimising the build-up of "fugitive" emissions from paints, sealants, insulation, volatile organic compounds, VOCs and even microbial gases due to moisture (MVOCs). Producers have, however, made progress in manufacturing improved materials, and today we have so much knowledge that we can "phase out" the emissison problem if we select the right materials.

5. Building procedures

While a high standard is observed in all aspects of interior design to assure maximum comfort of office workers or pupils, e.g. lighting, acoustics, humidity and temperature control, the following specific features are presented as worthy of special recognition.

Building materials are common sources of VOCs or of particles, including MMMFs. Building materials which cover large areas (e.g. ceiling tiles) may absorb contaminants from other sources and subsequently release them into the interior space (the sink-effect). Building materials is therefore carefully chosen to minimise emissions, and protect against both particle and gas contamination during construction activities.

Biological contaminants (MVOCs) have been known to contaminate buildings because of improper control of moisture, water damaged materials during transport or storage on site, sources of humidification, and because of inadequate cleaning of drainpans and cooling coils. Consideration should be given to these problems in the design of the structure, including easy access to possible sources of biological contamination for proper maintenance.

Provision of a state-of-the-art air handling system to minimise the accumulation of particulate matter and trace gases and assure a working environmentwith the maximum possible air quality (Fig. 1).

6. Energy effkiency

The “no recycle” design basis introduces a difficulty with energy loss during the colder months. The cheapest solution to the energy recovery problem in such systems, so-called “recovery wheels”, requires an interconnection between the inlet and exhaust air duct-work, according to Khoury et al. [5] and Gorman et al. [6]. Since such interconnections are also excluded by the design philosophy, an innovative solution is required. SP in Borås, Sweden has published a report in 1995, concluding that the amount of outside air has to be increased by 20 % if we prefer to use such recovery wheels [7]. This is provided by a system of indirect heat exchangers utilising a recirculating glycol-water medium.

The system provides 52 % recovery of exhausted heat under design conditions, and requires no physical connection between clean and contaminated air streams. The fact that recovery wheels offer a much less costly alternative serves to illustrate the “environment first” philosophy employed throughout the project.

Inadequate supply of outdoor air to occupied spaces in offices, kindergartens and schools is a common cause of indoor air quality complaints. The outdoor air ventilation rate for schools is 14 l/s per pupil or about 415 l/s per room (appr. 60 m^2/31 persons). In offices it is 4.2 l/s per m^2 + a security factor of 30 %.

7. What are total costs?

The annual costs for running a modern office building consists of the building and equipment depreciation on invested capital costs (6 %) plus operational costs, i.e. energy, cleaning and maintenance (2.7 %). When a new building is being planned, it has become common to use total annual costs as a decision-making tool. Operating costs increase relatively with the building’s age, particularly labour and energy costs.

In the past, annual costs have been evaluated per square meter floor space, related to the building costs **only** and not to the employees working in the building, representing 91.3% of total annual costs.

But why do we put up an office building in the service industry in the first place? Of course it is because there is work to be done, and this can be done in a less expensive way if the temperature feels comfortable and the indoor air quality is high. This contributes to high productivity. A good indoor air quality and the best total indoor environment are the most important factors for improving the efficiency of any staff. Total costs must be related to the sum of wage-related costs and building costs. This is shown in the Oseberg complex in Bergen (Norsk Hydro) where annual personnel-related costs per square meter are NOK 14,882 (USD[2] 1,957) (1998).

	Alternative I "IAQ std."		Alternative II "IAQ top"	
Capital costs (depreciations)	**USD 203**	8.8%	**USD 222**	9.4%
Thermal energy (HVAC)	**USD 11**	**0.5%**	**USD 11**	**0.5%**
Cleaning	**USD 21**	0.8%	**USD 14**	**0.8%**
Wage-related costs	**USD 2,081**	89.9%	**USD 2,096**	89.3%
	USD 2,316	**100%**	**USD 2,343**	**100%**

1US$ = **NOK 7.55 (10. February 1998)**

Table 1. The difference in total costs between "indoor air quality (an important part of IEQ)(IAQ) Top" and "IAQ Standard" is marginal due to wage-related costs. This example is from the oil company Hydro in their Oseberg building in Bergen, where they say that only 0.6 % increase in productivity may pay for the difference in employed IEQ standard.

The total costs of an IEQ standard, 7.5 cubic meters per square meter per hour (2.1 l/sec per person), is USD 2,316 (Table 1). If we raise the standard to 15 cubic meters per square meter per hour (4.2 l/sec per square meter) and take precautions with selection of materials, building procedures, cleaning procedures (CPB), etc., the costs will rise to USD 2,343, and the difference is mainly in investment costs: 9.4 - 8.8 = 0.6%. The personnel-related costs dominate totally (89.9 to 89.3% for the two alternatives).

8. Value of indoor air quality to productivity

In most buildings in the service industry wages and wage-related costs represent 85-90 % of the total costs per work station, and the increase in value is completely

[2] **1** USD = NOK 6.65 (**May** 1995)

dominating the total economy. Our most important challenge in planning new and refurbishing old buildings is to create an excellent environment for productivity as well as for health and comfort.

In the USA and in Norway there have been some studies since the late 1980s concerning productivity related to indoor air quality and indoor environment [1, 2 , 3]. The most comprehensive was carried out by Dorgan Associates, Inc., prepared for National Energy Management Institute in USA (NEMI):

"The conclusion of this study is that improving indoor air quality and indoor environment will provide a high return on investment through productivity gains, health savings, and energy reductions. The minimum direct annual employee productivity benefit of $55 billion is feasible by implementing a nation-wide effort to maintain indoor air quality at the level recommended by current scientific knowledge. The benefits of improved IAQ/IEQ are improved productivity, increased profits, improved employee-customer-visitor health and satisfaction, and reduced health costs.

The benefits of improved IAQ/IEQ are so large that this opportunity cannot be ignored. The challenge is to develop a sound and workable plan to implement the link between indoor air quality and productivity.

Anaverage simple payback of 1.6 years is achievable from the total productivity benefits. The improvements in many buildings will have a payback of less than 7 months. Almost all improvements to the environmental systems identified in this study have initial costs that are offset within the first two years through productivity, health, and energy benefits.

In addition to the productivity, health, and energy benefits, there are indirect, long-term, and societal benefits that have not been quantified in this study. Among these types of benefits are:

- Monetary benefits from increased profits and sales in retail buildings
- Long term societal benefits from an overall reduction in work related job stress, gains in worker health, and thus, increased worker productivity

The health and productivity benefits will offset all energy efficiency implementation requirements in buildings today. Some measures, in particular increased make-up air, could be inappropriately implemented in a manner that would increase energy use. However, the economic benefits from health and productivity gains allow the implementation of a comprehensive energy conservation design or energy management practice that reduces the total energy consumption. Energy conservation measures are no longer required to pay for themselves through a direct energy economic offset."

9. Conclusions

For years to come our most important work will be to find documentations of economic benefits of improving indoor air quality and climate. Less work should be put into calculation of the cost of absenteeism compared to productivity loss when we are at work. If you go to work and still have reduced work efficiency, it might be reasonably easy to estimate the value of indoor air quality towards productivity.

We might benefit from asking questions, like:

- What does it cost the private and public economy **not** to have an excellent indoor environment?
- What does reduced work activity while you are at work cost?
- What does it cost society when children and students have reduced learning ability due to indoor air quality and climate?

References

1. Haukenes, J.P. (1989) ***Arskostnadsvurderinger*** for *Investering*, Drift og Vedlikehold- Produktivitet. Kursdagene, NTH, Trondheim, 4-6 January 1989. (In Norwegian).
2. Kroner, W.M., Stark-Martin, J.A. and Willemain, T. (1992) ***Using Advanced Office Technology to Increase Productivity: The Impact of Environmentally Responsive Workstations (ERW's) on Productivity and Worker Attitude,*** Troy, NY, USA: Center for Architectural Research, Rensselaer Polytechnic Institute, 121 pp.
3. Dorgan Associates Inc., Madison USA (1993) ***Productivity and Indoor Environmental Quality Study,*** National Energy Management Institute, Alexandria, VA, USA, August 1993.
4. Hedge, A., Erickson, W.A. and Rubin, G. (1993). Effects of Man-Made Mineral Fibers in Settled Dust on Sick Building Syndrome in Air-Conditioned Offices, ***Proceedings of Indoor Air '93,*** Vol. 1, pp. 291-6, the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 4-8 1993.
5. Khoury, G.A. et al. (1988) An Investigation of Reentrainment of Chemical Fume Hood Exhaust in a Recovery Unit. ***American Industrial Hygienic Association Journal,*** Vol. 49, No. 2, pp 61-65.
6. Gorman, R.W. et al. (1984) Cross Contamination and Entrainment. ***Ann. of the American Conference on Governmental Industrial Hygiene,*** Vol. 10, pp.115120.
7. Carlsson, T. et al. (1995) ***State of the art, Investigation of rotary air-to-air heat exchangers,*** Swedish National Testing and Research Institute, SP Report 1995, 24 p. (In Swedish, English abstract).

Sustainable development also means healthy building

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Abstract
An important dimension in the application of sustainable development principles to the building sector is that concerning health risks related to the occupation of buildings. Today we are constructing buildings that will still be used in decades to come, and the recent examples of public health crises related to buildings oblige us to adopt a cautious approach based on the analysis and management of the risks involved, and driving us closer towards the mythical “zero risk” level.

Even if water supply is also one of the potential sources, this contribution proposes to mainly concentrate on the risks related to the air and the indoor environment, where the risks are numerous and varied.

After listing the various families of contaminants and sources of contaminants that can be found in buildings, some important examples are given: nitrogen oxides given off by heating appliances and gas cookers, and also by people through cigarette smoking; chemical atmospheric pollutants, which are also found in buildings; biocontamination of the air by all families of micro-organisms present in the air; allergens associated with complex mixtures of pollutants; radon, which can be concentrated in homes.

Considering this environment that is particularly open to the outbreak of public health crises and due to the numerous uncertainties, methods for assessment and management of risks have been developed. The general principle of these methods is explained here. Assessment is based on four elementary stages: identification of the danger, determination of the relation between the dose and the effect, estimation of public exposure, and lastly characterisation of the risk. Much work remains to be carried out on these four stages before they can be capable of clearly defining the priorities for defining risk management. In this situation, the possible recommendations must be considered in strategic rather than operational terms.

In particular, it appears important to create places of exchange where building trade professionals, users and public health professionals can learn to work together to develop, with a total independence of their scientific expertise ensured by an appropriate status, monitoring and alert procedures, capacities for informing the public and the players concerned, and also recommendations to enable public powers to act according to needs and constraints.
Keywords: building, environment, sustainable development, health, comfort, risk assessment.

1. Introduction

The act of building in a context of sustainable development must aim to meet the needs of the present without compromising the capacity of future generations to meet their own needs. The analyse of the implications of this principle is both complex and difficult: complex, because the interactions between the building and the environment are numerous; difficult, because the very concept of sustainable development is variable [1].

A first dimension is that of the impacts of act of building on the use of non-renewable resources (including energy resources) and on the quantities of wastes and effluents. A second dimension is the search for a certain harmony between the built environment and the natural environment. However, another dimension, and not one of the least important, concerns the health risks related to the occupation of buildings, and even what could be called a “protective hygienism”.

As a matter of fact, against a background of increasing public awareness of risks, due to recent highly publicised issues such as lead paint, asbestos or wood dust, many people are more and more concerned about health and hygiene problems related to building.

In fact, this question should be considered in its numerous aspects, well beyond just these notable examples, firstly, because people are spending more and more time within the confined spaces created by buildings, and secondly, because the annual rate of new construction only represents an infinitely small part of the building stock and therefore around one year will be necessary to completely renew the stock. This issue of the “close ecosystem” of the man must supplement the issue of the ecosystem of the world.

Therefore the principle of precaution obliges decision-makers and scientists to anticipate the risks and to define the best way of identifying them. Food, water and air, and even electricity, are potential sources of risks. While the first two are relatively well identified, we must now try to control the other two as much as possible.

This contribution proposes to concentrate mainly on the issue of risks related to the air and to the indoor environment.

2. What are the risk factors?

2.1 The main sources of pollutants

European directive 89.106, which specifies the essential requirements for buildings and building products, indicates the families of contaminants and/or potential sources of contaminants to be considered and establishes a general framework for identifying the sources of contamination. The indoor environment, water supply, sewerage, solid waste disposal and the external environment are the various targets of the approach.

On examining the risk factors related to the indoor environment, we find that the sources are multiple and varied. Most of them are related to the quality of the indoor air [2], while another important factor concerns sources of noise (external noise or noise from another enclosed space, impacts, services plant, etc.) and vibrations. In addition, although they are not strictly considered as contaminants, lighting, air humidity and the thermal environment are some of the parameters that can influence the immediate physical environment of the occupants of buildings, and some of them can also affect the future transition of contaminants and the activity of the sources.

Contaminants that can affect the quality of air can come from the following [3]:

- building materials, particularly all those that are in direct contact with the indoor air, such as floor and wall finishes and paints.
- technical services installations such as hot water distribution systems or combustion appliances,
- furniture, fittings and hardware,
- external atmospheric sources,
- the ground on which the structure is built,
- occupation of the building (people, domesticated or non-domesticated animals, plants),
- activities inside buildings (cleaning, maintenance work, painting and varnishing, use of pesticides, cooking meals, etc.).

2.2 A wide variety of contaminants

To this variety of sources corresponds a varied list of contaminants, which we can attempt to group together as follows:

- products of the human metabolism (water vapour, body odours, etc.),
- products of combustion (water vapour, carbon monoxide, NO_x, CO,, hydrocarbons),
- tobacco smoke,
- volatile organic compounds (several hundred individual compounds included under this generic term: formaldehyde, solvents, etc.),
- viable particles and biocontaminants (allergens, moulds, bacteria, viruses, toxins, etc.),
- nonviable particles such as fibres and particles in suspension,
- radon and other radioactive substances,
- emissions from electric and electronic equipment (electromagnetic fields, ozone, etc.).

2.3 Some examples of contaminants and risks

2.3.1 Nitrogen oxides

Nitrogen oxides (NO) are among the main atmospheric pollutants [4]. In the indoor atmosphere, the main emitters are heating appliances and gas cookers, and also cigarette smoking. Note that the indoor air partly reflects the exterior air.

In a nonpolluted rural environment, the basic level is around 5 $\mu g/m^3$. Values in urban areas are very variable. The content in an indoor atmosphere are on average less than in an external atmosphere, but it is highly variable. Thus, 10 cigarettes smoked in a 30 m^3 room will lead to levels of 40 to 80 $\mu g/m^3$. Similarly, in a poorly ventilated kitchen, very high peak values can occur when the gas cooker is functioning.

The effects on health vary from reactions of acute discomfort to chronic illnesses such as asthma or chronic bronchitis. Epidemiological studies published concerning long-term exposure suggest a relation with an increasing risk of illness of the lower respiratory tract in children. The risk increases by around 20% for every 30 μg/m^3. As regards the risks to adults or the impact on breathing, the relation is less clear.

2.3.2 Atmospheric chemical pollutants

The quality of an indoor atmosphere depends largely on the nature and the concentration of indoor sources of pollution and the ventilation conditions. However, the external inputs of pollutants must not be neglected. Their contribution varies according to climatic conditions, the location of the building and the situation of air intakes in relation to external sources of pollution [5].

In France, the most representative exposure data concern offices of the tertiary sector and school and university areas; housing has been studied very little. Similarly, there is virtually no information available for public recreational buildings (theatres, cinemas, etc.) or for sports facilities (sports halls, swimming pools, etc.) although we know that the organism is more sensitive to atmospheric pollutants during physical exercise.

Despite a certain effort in recent years, many subjects remain to be examined or to be studied in greater depth. Modelling approaches appear to be promising, particularly in terms of cost, on condition that better knowledge of the interactions between pollutants and between pollutants and surfaces is previously acquired.

2.3.3 Biocontamination of air

All families of micro-organisms are present in the air: bacteria, microscopic moulds, viruses, protozoa, etc. [6, 7, 8]. These micro-organisms and their metabolites (endotoxins, mycotoxins) can be the cause of infectious diseases (Legionnaire's disease, aspergillosis, etc.), immuno-allergic disorders (asthma, hypersensitivity of the lungs, inhalation fevers, etc.) or toxinic problems. They are also some of the possible causes of the "Sick Building Syndrome" [9], whose mechanisms are still unknown.

Biocontamination of the air varies greatly with time and depends on several factors: technical factors (air filtration, water stagnation, air renewal and communication with the external air), environmental factors (indoor humidity conditions, density of occupation of the areas, presence of plants, behaviour of the building materials [10]) and climatic factors (weather conditions, seasonal variations, etc.). Since the respective influence of these different factors is not yet modelled, normalisation concerning a strategy for realistic assessment of exposure would be difficult in the present state of knowledge.

2.3.4 Allergens associated with complex mixtures of pollutants

Experimental work and epidemiological studies in recent years suggest that there may be an increasing sensitivity to biological contaminants such as allergens, under the influence of various pollutants, some of which are mainly components of urban air pollution [11].

Biological pollutants of buildings are mainly acarids (dust mites), allergens carried by animals, and moulds. Dust mites are mainly found in homes and especially in bedrooms. They can be quantified by quantitive analysis of a marker present in the faeces. Animal allergens have also been quantified, such as those of the cat, found in the dust of classrooms or shopping centres, or of the dog, or those of rodents present in litters but also in floor dust, those of cockroaches in floor dust and in kitchen cupboards. Moulds can develop inside homes on substrates of vegetable or animal origin. Biological pollution also includes bacterial endotoxins, which have been involved in the increase in asthma in housing.

There are many chemical pollutants present in rooms, which are believed to be closely linked to allergic disorders:

- NO,, present in poorly ventilated kitchens with peaks from 400 to 1000 ppb, causes accentuation of the bronchopathy induced by the inhalation of dust mite allergens. The use of gas cookers is recognised as a possible cause of the increased risk of certain respiratory symptoms in adults, such as wheezing, laboured night-time breathing or attacks of asthma.
- The concentrations of volatile organic compounds (VOC) in the indoor air are 2 to 10 times higher than those of the external air. The rates of formaldehyde are particularly high in new houses containing urea-formol foams for less than three years. A recent study showed that, for an asthmatic person, there was a significant relation between the asthma symptoms and the measured concentration of VOC.
- The ozone present in rooms comes mainly from external sources. The effects shown in humans (bronchospasms, increased bronchial hyperreactivity) are mainly found in cases of external exposure due to the associated physical exercise. Several experimental studies show greater sensitivity to the immediate reaction induced by an allergen after prior exposure to ozone.
- During SO, peaks that can be attained when using gas radiators, asthma sufferers can have a bronchospasm.
- Tobacco is a major source of many pollutants, including nitrous oxide and aldehyde oxide. Passive smoking can cause non-specific bronchial hyperreactivity and greater severity of symptoms in asthmatic children.

2.3.5 Radon

Radon 1s a radioactive gas that is omnipresent on the Earth’s surface. On disintegrating, it emits alpha particles and engenders solid radioactive offspring that attach to particles in the air, causing lung exposure during inhalation. By different physical processes, it migrates from the ground to the atmosphere, and it can accumulate in the more confined atmosphere of buildings. Radon represents slightly more than one third of the average radiation exposure of people in France, i.e. 65 Bq/m^3 [12].

However, exposure levels are extremely varied. Thus there are areas where the activity rates in terms of volume are particularly high (for example, in France, the Massif Armoricain, the Massif Central and Corsica). France, like Switzerland, Germany and Spain has an average rate three times higher than that of Holland or the United Kingdom, but half that of Finland or Sweden.

Radon is associated with a risk of lung cancer. It is estimated that a year spent in a house at 200 Bq/m^3 leads to a 2.5 10^{-4} probability of death due to lung cancer. Therefore it is recommended to envisage measures to be taken in existing housing above 400 Bq/m^3 and to avoid a rate of more than 200 Bq/m^3 in future housing.

An extrapolation on the basis of a sample of more than 10,000 measurements taken in France in 1997 showed that around 300,000 homes exceed 400 Bq/m^3, and action taken for these homes would have an effect on around 20% of the general public risk.

3. How can we assess and manage the risks?

3.1 Many uncertainties, but a particularly favourable environment

Considering the numerous uncertainties highlighted above, it can be seen that buildings offer a particularly favourable context for the emergence of public health crises. Note must be taken of the following elements:

- Most risk factors are not perceptible (pathogenic micro-organisms, cancerigenic or toxic substances, ionising or electromagnetic radiation, radioactive substances, etc.).
- The exposure to contaminants in the air is omnipresent and generally involuntary.
- The effects on health are still uncertain whereas they are clearly not generally accepted by the population since buildings are considered as protective places. The levels of requirements, which in fact correspond to the search for the "zero risk", are thus much higher here than in any other field (such as for instance transport). Moreover the risks appear related to technologies and the populations at risk are especially children and old people. To the issue of community risk, it should therefore be added the issue of individual risk.
- Lastly, scientific and technical data, which is often very complex, limits communication between experts and the public on the risks involved.

Faced with this situation of uncertainty and complexity, methods for assessing and managing the risks have been developed.

3.2 Risk assessment

Risk assessment is a method for summing up and analysing available information concerning the toxic properties of a substance or an agent [13]. It is based on four elementary stages: identification of the danger, determination of the relation between the dose and the effect, estimation of the exposure of the populations, and characterisation of the risk.

3.2.1 Identification of the danger

This is mainly a qualitative stage that aims, according the available scientific data, to draw up the list of dangers associated with a chosen environmental agent and to give an indication of the plausibility of each of them.

3.2.2 Determination of the dose-effect relation

In this stage, the risk is determined for a given level of exposure to a toxic substance present in the environment. This assessment is based on relatively high levels of exposure, obtained in animal experiments in a laboratory or, for exemple, during high exposures of workers in their working environment. Then the probable effect is estimated by extrapolation, for the same population, at very low levels of exposure for which no data is available. Naturally, this must also take into account the differences between acute effects that occur after a short time due to high dose rates, and the chronic effects resulting from prolonged or repeated exposure at very low dose rates. Moreover it must be raised the problem of the type of extrapolation to apply: linear or threshold effect extrapolation? At last how to take account of accumulation effects which must not be neglected in the case of some contaminants (for example asbestos fibers)? All the uncertainties related to this approach imply that, in the end, a wider basis of investigation must be developed.

3.2.3 Estimation of the exposure

This stage concerns the identification of the populations potentially exposed to an agent, by relevant groups of age and sex. A very dangerous product for which the probability of exposure is zero does not pose a public health problem. On the other hand, a widespread factor - even if it is relatively harmless - of a frequent illness can be responsible for a large number of cases of this illness.

The identification of sources of pollution (building materials, ventilation system, presence of allergens, etc.), of the concentration of pollutants emitted, their frequencies, their stages of transition (air, water, food) and their level of impact on the target organisms are therefore key elements for the assessment of the exposure.

The exposure is estimated on the basis of various information, from measurements to mathematical modelling.

3.2.4 Characterisation of the risk

All the results of the above stages must then be to characterise the risk and provide elements for interpreting the scale of the risks in question. Although, in practice, the risk is often only characterised by a probability, the analysis of the risk implies many other factors that are necessary for management of priorities.

3.3 Management of priorities

To guide public health measures, there is a standard formal framework for determining the priority problems. The importance of a health problem is judged on the basis of epidemiological indicators such as the incidence and prevalence, the relative risk and attributable risk [14].

In general, two other parameters are considered to define priorities: the social perception of the problem and the existence of effective solutions.

The application of this framework to the sector of health risks related to the environment in general, and to the indoor environment of buildings in particular, raises many questions due to the complexity of the relationship between the environment and health.

People spend a large part of their time inside buildings. Therefore, as we have seen, the factors of exposure that are responsible for low risks on the individual level can nevertheless produce considerable risks in terms of public health, because of the size of the population exposed and the period of exposure. Characterisation of such exposure is complicated by the large number of sources of pollution within buildings and the wide temporal and spatial variations of contaminants present in housing.

Due to the existing scientific uncertainties, the incompleteness of available information and the structural weakness of the buildings-public health relation, it is not possible to reach a clear definition of priorities incorporating the protection of the occupants' health. In this situation, the possible recommendations must be considered in strategic more than operational terms.

For example, the objectives to be given priority in this context would be as follows:

- To increase awareness of all decision-makers by developing public research programmes, by providing information on exposures and by training and education.
- To deal with the most visible problems that can cause crises, for example, by establishing criteria for authorising the sale of new materials and products, launching maintenance programmes for ventilation systems, specific actions to be taken in sensitive places such as day nurseries, schools and hospitals.
- To introduce into the assessment procedures for innovative products (such as the procedure "Avis Technique" in France) some items which will enable a health risk assessment.
- To develop a policy of seals of approval with appropriate economic incentives to encourage the application of technological improvements that decrease risks in new buildings.
- In particular, it appears important to create places of exchange where building trade professionals, users and public health professionals can learn to work together to develop procedures for monitoring and alert procedures, capacities for informing the public and the players concerned, and also recommendations to enable public powers to act according to needs and constraints.
- To ensure, through an appropriate status, a total independence of the scientific expertise in the health domain.

4. Conclusion

The service life of a building is generally several decades (or even several hundred years). Recent cases of public health crises related to buildings, such as the asbestos crisis, show that it is very difficult to take action when sources of contamination in place in buildings become unacceptable due to both improved knowledge and changing requirements. Therefore it is very desirable to monitor potential sources of contamination at the earliest stages of the building process. This concerns product specifications and also construction systems and techniques in general, including maintenance and servicing.

The relationship between health and the quality of atmospheres inside buildings is a very wide-ranging and complex subject. It covers several areas of expertise, in the medical world and in building. Doctors, engineers and technicians must work more together in closer coordination. Their complementarity is more indispensable today, because knowledge has progressed in both medical and technical fields. However, many scientific uncertainties remain, which can only be gradually resolved by increasing research in all the fields concerned.

5. References

1. Bourdeau L., Halliday S., Huovila P., Richter C. (9-12/6/97) Sustainable development and the future of construction, a CIB W82 project. 2nd *International Conference on Buildings and the Environment.* CSTB-CIB, Paris.
2. World Health Organisation (1993) Indoor air pollutants: exposure and health effects. *EURO Reports and Studies n°78*, WHO Regional Office for Europe, Copenhagen.
3. Cochet C. (29/10/1997) Les principales sources de contaminants dans les batiments. *Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
4. Cabanes P-A. (29/10/1997) Les oxydes d'azote et la sante. *Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
5. Le Moullec Y. (29/10/1997) Evaluation de l'exposition aux polluants chimiques atmosphériques dans les batiments. *Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
6. Parat S., Perdrix A. (29/10/1 997) Aerobiocontamination dans les immeubles de bureaux. *Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
7. ASTM (1990) Biological contaminants in indoor environments. *STP 1071*, Philadelphia.
8. Nevalainen A. (1993) Microbial contamination of buildings. *Indoor Air 93*, Vol. 4, pp. 3-16.
9. Raw G.J. (1995) A questionnaire for studies of sick building syndrome, a report to the Royal Society of Health Advisory Group on Sick Building syndrome. *BRE Report,* Garston Watford.
10. Robine E., Derangere D. Testing procedure for evaluation of microbial contamination of building materials (9-12/6/97). *2nd International Conference on Buildings and the Environment.* CSTB-CIB, Paris.
11. Pauli G., de Blay F. (29/10/1997) Allergenes et melange complexe de polluants : quelle synergie *? Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
12. Hubert P., Pirard P. (29/10/1997) Exposition au radon dans l'habitat en France. *Colloque ADEME-APPA-CSTB "Batiment et Santé",* Paris.
13. Kirchner S. (29/1 O/l 997) Les methodes d'évaluation des risques sont-elles applicables aux environnements interieurs *? Colloque ADEME-APPA-CSTB "Bdtiment et Santé",* Paris.
14. Dab W. (29/10/1997) Comment definir et gérer les priorités de sante publique relatives aux batiments *? Colloque ADEME-APPA-CSTB "Bdtiment et Santé",* Paris.

Glazing analysis in a cristal palace

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Abstract
The aim of this paper is to demonstrate several conflictive aspects in the application of the sustainable concepts in the air-conditioning systems depending on the different geographic and climatic characteristics,

The showed study is corresponding to a Crystal Palace situated in Madrid (Spain), and the paper explain the different alternatives of actuation in the design of an air-conditioning system from a traditional point of view and from a sustainable concept's vision.

This big building is completelly built of glass, and the solar irradiation gains provoke than the indoor environment would be extremelly inadequate to human requirements, because the indoor temperature goes beyond the 60ºC.

We have realized the thermal modelization of the building, during single days and during short periods in summer and winter. The most interesting aspects appear in central summer days.

After this study and discussion of the results, the alternatives wich only comprise the installation of indoor air-conditioning systems is not enough to assure the appropriate indoor environment, including the use of radiant floor and a system to introduce fresh air inside the building.

It seems clearly that the most convenient alternative is changing the external glass although this solution neither is excellent.

One conclusion is that in hot countries is not enough the indoor air-conditioning systems to adequate the indoor environment of glazing buildings exposed to high direct solar radiation.

The unique sustainable solution must be to provide external elements to minimize the solar influence into the indoor-environment.

The final conclusion is that sustainable aspects should be defined in according to the different geographic regions, and the scientific and technical background of this question mustn't be done without consider the different aspects and different points of view depending on the origin and experience of the appraiser.

Keywords: geographic aspects in sustainability, solar radiation, sustainable indoor environment, use of existing buildings

1 Introduction

The aim of this paper is to demonstrate several conflictive aspects in the application of the sustainable concepts.

The first one is the different needs and implications as a result of the different building's performance according to the climatic characteristics depending on where is situated the building.

We try to demonstrate that relations between sustainable development and indoor environment, besides difficult are different depending on the particular country problems.

Finally, we try to demonstrate the difficulties to develop a common science background in this area.

The building case study is placed in the city of Madrid, on the centre on Iberian Peninsula. The building is situated in the *Parque del Retiro,* beside to the Buen Retiro Palace, royal residence of Felipe IV in the XVII century.

The Crystal Palace was built on 1887, and originally this building was a greenhouse to cultivate tropical plants.

In the last years this beautiful Crystal Palace was hardly used and the building was on full decline.

Recently the City Council of Madrid worked on a big plan to promote the reutilisation of historical existing buildings [1]. Inside this plan and with the aim to increase the use of the Retiro's Park facilities, they decided to adapt the Crystal Palace to a multifunctional space, dedicated to host cultural events like art expositions, editorial presentations or inaugural conference events, according to objectives of the initial plan.

The Spanish Ministry of Education and Culture ordered to different professional consultants the realisation of several parts of the reconstruction project.

This paper is based on the study and discussion of the air conditioning implications had in the reconstruction project of this building.

2 Environment conditions

2.1 Building characteristics

This crystal palace comprise only one big space (see Figure 1). The maximum height are the 25,25 meters of the dome. The lowest part of the building has 6,25 meters high.

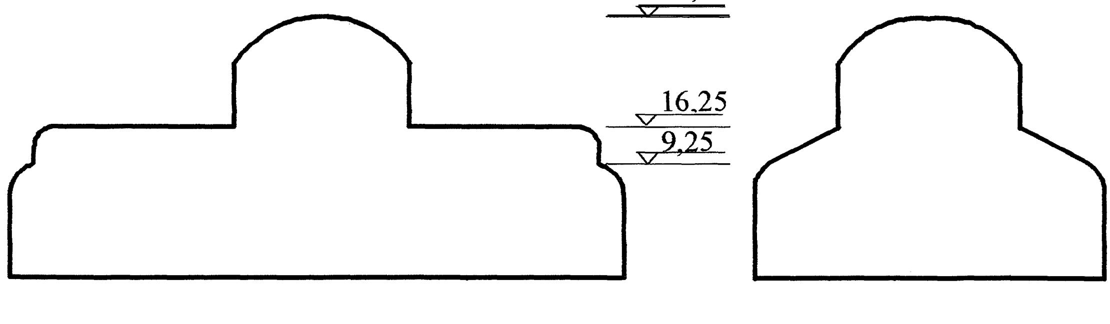

Figure 1. Schematic draft of the building (elevation and cross section)

The surface plant of the building is $1200m^2$. So, the total volume is approximately $17.000m^3$.

The complete building skin (façades and roofing) is made of simple crystal with a conductance of 166 W/m^2ºC and solar transmitance of 0.78 built-in over the original steel structure.

2.2 Regional climatic aspects

Madrid is placed on 40.48 Northern latitude and 595 meters over the sea level.

In summer the climatic conditions [2] are: a dry design temperature of 35.5ºC, and this temperature is overcome on 1% total times. The most probabilistic exterior humid temperature is around 21ºC.

In winter the dry design temperature is -4.2ºC, and the 1% of total times this value are overcome. The relative humidity is 95% and the prevailing wind is in the northern direction with a medium speed of 4.4 m/s.

2.3 Desired indoor climatic conditions.

Due to the Spanish regulations [3, 4], the indoor design climatic conditions have been fixed in 25ºC on summer. So, it's necessary to introduce corrective elements to provide an appropriate indoor environment in order to develop correctly the various possible events inside the building.

3 Analysis Methodology

In order to simulate the thermal ambient behaviour of the building we have used the program TAS.

The used methodology consists on dividing the total volume of the building in horizontal volumes. This division is shown in the Figure 2. Obviously, and checking the results, we didn't want to climate the complete volume of the building.

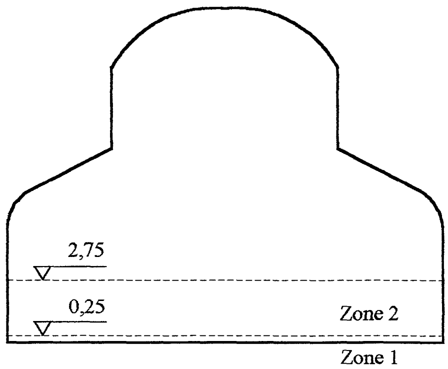

Figure 2. Schematic section draft of the building with mean zones of the model

We want to assure that the indoor environmental conditions of the 2nd zone (occupied zone) fullfil with the regulations and provide a correct indoor environmental conditions.

The zone 1 (radiant floor) is also important for the study. The 3rd zone is outside the possibly occupied zone (more than 2,5 meters of height).

The program calculate the temperatures distribution, the air movement, the needs of air impulsion taking in account the internal heat generations, the solar radiation aportations and the gains and loses by conduction in the different parts of the building [5].

Furthermore it is possible to define a combination of different systems in order to adapt the indoor environment of the building with this methodology and we are calculating different alternatives to air-conditioning the building.

In addition, this methodology response against a focused conditions fixed by a weather file where have been included the different weather magnitudes for all days of the year.

4 Discussion

4.1 Actual state

The first simulation was developed for a warm summer day (for instance August 7th) on the building in this actual conditions. The results of the simulation were that the temperature in top of 1st zone (floor) was 60.6ºC and the resultant temperature in 2nd zone was 62.5ºC.

When the simulation was done in dynamic conditions (during a period of five days before august 7th) the results were that the floor temperature was 64.9ºC and the indoor temperature was 65.6ºC. It seems clear that it is impossible to develop some human activity inside this building with these conditions.

4.2 Adding an air-conditioning system

The adopted solution was to provide an air-conditioning system formed by a radiant floor to regulate the floor temperature and adding cold air impulsion to compensate the insufficiency of this first system [6].

The floor radiant power necessary to assure than the floor will be at 18ºC in the central hours of the day is aproximatelly 375kW (over 300W/m^2).

For an usual value of aprox 36 W/m^2, the total power we want to obtain is 42.4 kW. With this power the floor temperature at central hours of the day is 25ºC.

The temperature in the occupied zone with this second case arrive to 34.4ºC (see Figure 3) at midday hours of the day, including an air impulsion of 35kg/s and 15ºC. If the air impulsion grow up, the temperature decreases slowly. For instance increasing the impulsion from 17 kg/s to 35kg/s the temperature decrease 1.5ºC.

With these conditions the required power plant had a power higher than 300 Kw and furthermore, it response is clearly insufficient.

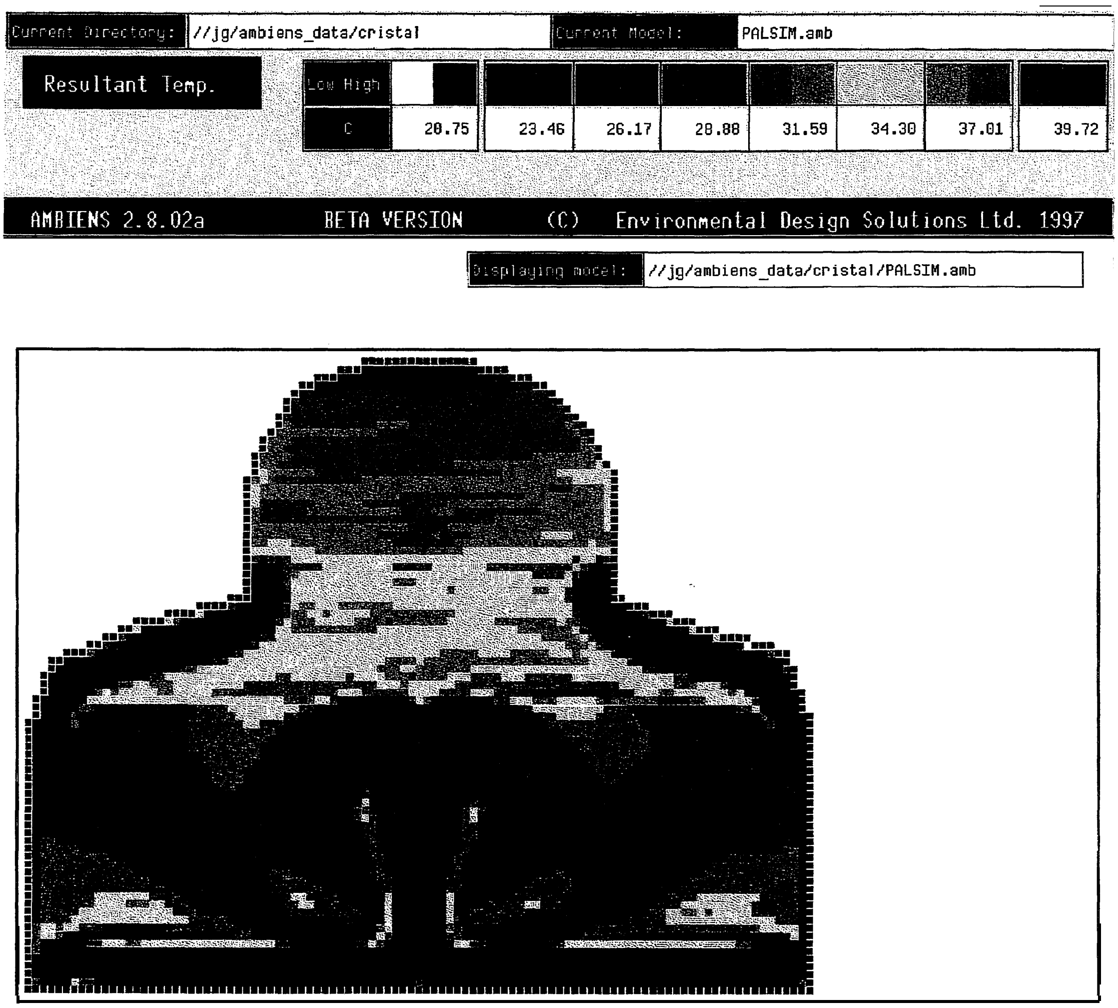

Figure 3. Indoor environment simulation with air-conditioning system.

With this case it is clearly demonstrate that only with air-conditiong system is impossible to air-conditioning this building.

4.3 Adding an air-conditioning system and changing the glass in the external skin
We decided that the solution should be to change the physical conditions of the building. So, we choose a new glass for the windows and the roof. The new glass has a solar transmitance of 0,37 and a conductance of $146W/m^{2}$°C. We can see the excellent behaviour of the new glass in front of the solar radiation.

With this new glass and in comparison with the last study we could observe that in this case the midday resultant temperature in the occupied zone is around 30°C (see Figure 4) with an air impulsion of 17kg/s and a radiant floor of 42,4 kW.

In this case and for these conditions the necessary cold production plant should have a power of 107 kW.

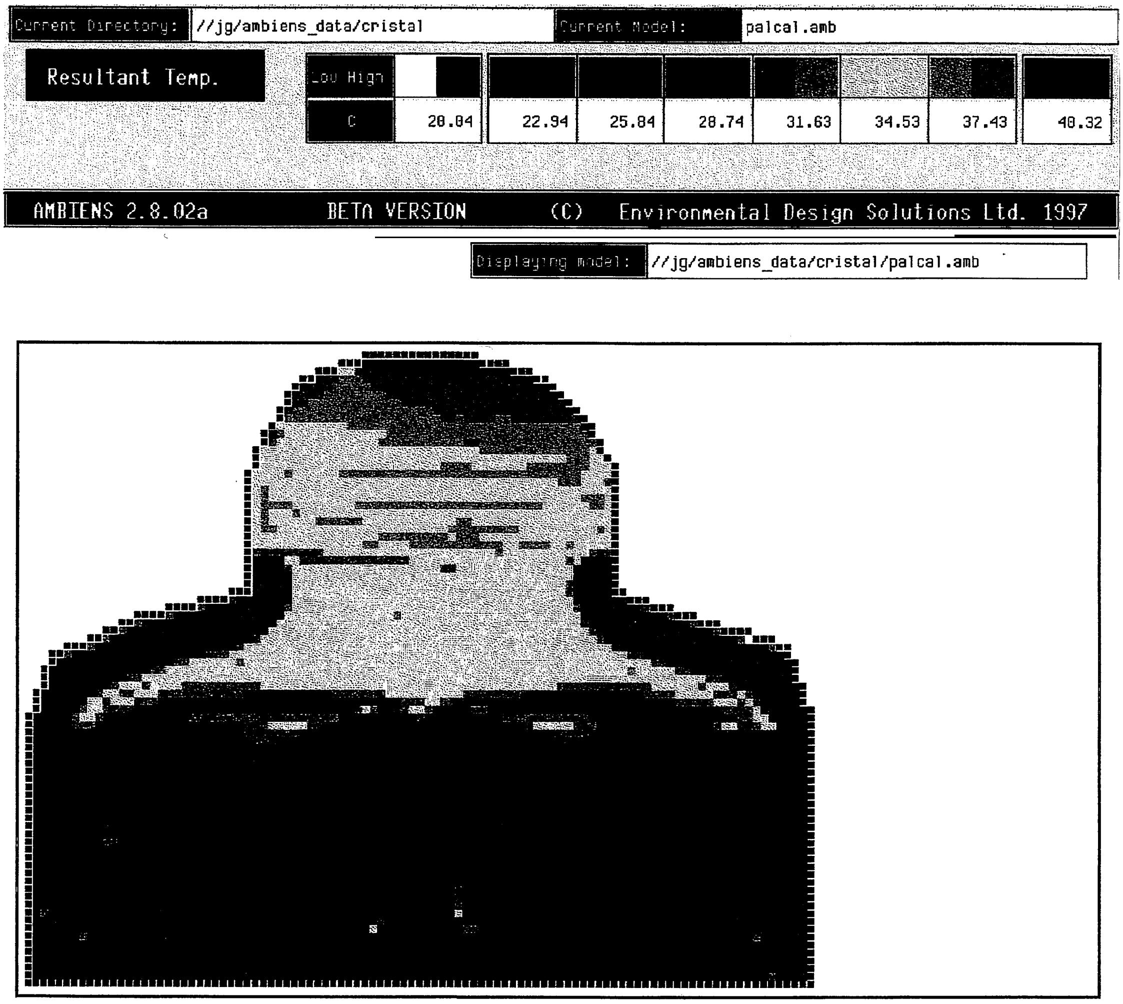

Figure 4. Indoor-environment simulation with air-conditioning system and new external glass

4.4 A traditional discussion versus sustainable discussion

From a traditional point of view we would have done a comparison between the cost of installation of the two options, adding the cost of consumption associate each solution and the cost of changing the glass. With all these costs and prices, and depending on the rate of return in years, the property would have decided.

From this point of view, the price of the glass would be recovered in aproximatelly three years.

From a sustainable point of view, we must to add the following aspects to this discussion:

- additional costs of production the elements (glass and air-conditioning production plants).
- cost of space (in the basement floor the space is strong restricted, and depending on the utilization of an air-conditioning plant or another plant would be important for the space saved).
- evaluation of the real needs to arrange the building, and if this arrangement is strictly necessari, may be is not necessary the building performance at warmed-up midday hours on summer.

5 Conclusions

In hot countries, the solution to avoid solar irradiation in buildings is provide an adequate sunshades in facades or externally to the buildings (in this case, we could use the situation in a park to provide a vegetal sunshades). Whichever other indoor solution don't response effectivelly to the user requirements and obviously, so it is not sustainable.

The most important conclusion that we can observe is the different implication of the different aspects in the evaluation of an air-conditioning system depending on the point of view from the appraiser.

If we want to introduce sustainable aspects in whatever evaluation, we should to consider a great range of aspects (from the use of spaces to the energy consumption in the production of systems).

Sometimes, depending on the particular problems of the country or the region, is difficult to use defined sustainable points of view. So, in cold countries the solar irradiation could be used positively to save energy in efficient energy buildings (lighting and heating), but in hot countries (for instance mediterranean countries) the solar irradiation could be the biggest problem.

The conclusion to this question is that sustainable aspects should be defined in according to the different regions, and the scientific and technical background of this question mustn't be done without consider the different aspects and different points of view depending on the origin of the appraiser.

6 Acknowledgements

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7 References

1. Dirección de Medio Ambiente Urbano (1995) *Madrid 21. A strategy for sustainable development in the Comunidad de Madrid,* Agencia de Medio Ambiente de la Comunidad de Madrid, Madrid (Final Resume in English).
2. Servicio Nacional de Meteorologia (1997) *Datos climáticos de España.* Servicio de Publicaciones del Servicio Nacional de Meteorologia, Madrid.
3. Ministerio de Industria y Energía (1986) *Reglamento de instalaciones de calefacción, climatizacidn y agua caliente sanitaria,* Secretaria General Técnica, Madrid.
4. Ministerio de Fomento (1994) *Norma Básica de la Edificación CT-79: Condiciones t&micas de los edificios*, Secretaria General Técnica, Madrid.
5. CIBSE (1990) *Guide Volum* A, Chartered Institution of Building Services Engineers, London.
6. ASHRAE (1995) *Handbook: HVAC Applications,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Guidelines for indoor air quality in schools: Creation of healthy indoor environment

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Abstract

This article describes a model for the way the authorities can disseminate research results relating to the indoor environment and health, so that they will be applied in practice in the form of advice and aids for the different players who exert an influence on the design, renovation and management of school buildings - with the aim of improving the indoor environment for children and young people.

Allergies are on the increase in the whole western world. According to "European white paper - allergic diseases as a public health issue", about 35% of the population of Europe is affected. In Sweden, one in three of all adults and four out of ten school children have some form of allergy. For young adults the figure is 50%. (Max Kjellman, Allergy Conference 96). The increase observed over the past decades shows no signs of abating.

There are a lot of indications that the indoor environment is a contributory factor in this worrying development. Several studies have shown the the indoor environment of children and young people in schools and day nurseries is the worst. In such environments there is an increased frequency of sick building symptoms, and many develop a hypersensitivity which becomes permanent. One important stage in bringing about an improvement in health that will endure in the long term is to prevent allergy and sick building symptoms in school by exercising strict control over the indoor environment.

Ever since the middle of the 1970s a large number of schools in Sweden have had to be renovated and prematurely demolished because the building had made children and staff ill. Nor is it sustainable to construct buildings that are not fit for their purpose.

The change to a society that is sustainable in the long term must comprise both indoor environment/health, resource economy and provision for recycling. Health issues in the indoor environment must be made a self evident part of the environmental adaptation which is now taking place in the construction sector.

In 1995, the National Institute of Public Health carried out a broad based information campaign, called Allergy Year 95. In connection with this, the Institute developed a knowledge base regarding the relationship between indoor environment and health, and disseminated research results and aids based on these which had the aim of facilitating the planning of healthy school buildings.

Two handbooks were published, "Methods for healthy renovation and management of schools", and "Methods of surveying school buildings with indoor climate problems, and remedial measures". These handbooks were presented to decision makers and school staff through a large number of local conferences held in collaboration between several authorities. They also constituted a common framework for international cooperation between researchers and authorities within ISIAQ. Within the framework of ISIAQ, a report is to be drawn up by the year 2000. The handbooks - with guidelines geared to different aspects - are intended for a number of different players who are involved in the physical environment of schools. They refer to three different situations in which it is particularly important to pay attention to the indoor climate: 1. The operational stage, 2. In conjunction with renovation (also mainly applicable for new building), 3. If climatic problems occur in a school.

Key **words:** Schools, indoor environment, allergy, guidelines, renovation, management, maintenance.

1. Introduction

1.1 Allergy - the public health issue of our times

Allergies are on the increase in the whole western world. According to "European white paper - allergic diseases as a public health issue", about 35% of the population of Europe is affected. In Sweden, one in three of all adults and four out of ten school children have some form of allergy. For young adults the figure is 50%. (Max Kjellman, Allergy Conference 96). The increase observed over the past decades shows no signs of abating. In order to counteract this development, preventive measures must be taken - especially in the environments of children and young people.

1.2 Knowledge and methods of prevention

There is a relationship between indoor environment and health. Allergic persons react strongly to sick building environments. Many develop hypersensitivity which becomes permanent.

In Sweden and the other Nordic countries, knowledge and methods of dealing with indoor environment problems in schools have been developed over several decades. In response to a government mandate in 1994, the National Institute of Public Health has produced information material on how a healthy indoor environment in conjunction with the renovation of school premises can be created and maintained. The material also contains advice on what to do when problems occur in the indoor environment. The information in both pulications has been disseminated to commissioning departments in the municipalities via conferences and seminars.

In the autumn of 1995, the Board of ISIAQ commissioned Inger Savenstrand Rådö, National Instituite of Public Health, Sweden, to form a working group and draw up "Guidelines for good indoor air quality in schools". An initial workshop was held in Nagoya in 1996 at which several countries expressed an interest in participating in the work. It is expected that the final report on this work will be published in the year 2000. The main purpose of the group's work is to describe measures for the creation of healthy school environments. At the seminar Healthy Building in Washington in September 1997, Inger Savenstrand Rådö presented methods for the creation of healthy buildings. The delegates agreed on the following statement: "Allergy and other hypersensitivities are the most common diseases among children and youngsters in the western industrialised world. It is therefore necessary to look upon the environment in schools from *an allergy point of* view to prevent pupils being sensitised (primary prevention) and to minimise the problems for pupils already affected (sensitised) (secondary and tertiary prevention) . . .."

13 The "Swedish model" - work for sustainable improvement in health

Through the establishment in 1992 of a new authority, the National Institute of Public Health, the task of which is to work for the improvement of public health and the prevention of adverse health effects, the allergy issue was given prominence and preventive work could begin. Knowledge at the scientific level can be translated into tools of practical utility and transferred to important target groups. Allergy issues were highlighted in a campaign year in 1995. The significance of the indoor environment for health was one of the areas. The cost of producing information material, arranging conferences and seminars was borne by the Institute.

A group of authorities was formed for collaboration on indoor environment issues. 14 authorities and organisations contribute with their spheres of responsibility regarding the indoor environment. The group includes the National Board of Occupational Safety and Health, the National Board of Housing, Building and Planning, the National Board of Health and Welfare, the National Association of Local Authorities, the Swedish Council for Building Research, etc. The National Institute of Public Health holds the chair in the group. The group is now making plans, together with industries and organisations, for a joint demonstration of indoor environment issues over a whole year - Indoor Environment Year 1999.

The Swedish Government is aware of the problems concerning poor school environments. Special funds have been made available for the upgrading and renovation of indoor environments in schools.

Many Swedish municipalites have passed political resolutions that an endeavour is to be made to create allergy-free environments. One in three municipalities have interdisciplinary groups, 'allergy committees', which have the aim of preventing allergies and making life easier for allergic persons. These groups provide the impetus and provoke interest in environmental issues, so that initiatives are taken to improve matters. The interdisciplinary composition of these working groups is an important factor in their work for healthy indoor environments.

The environmental debate in Sweden has long concentrated on utilisation of natural resources and less on the effect of air pollution on human health and the quality of life. Nor have indoor issues received enough attention in relation to the scope of the problem: on average, we spend 90% of our time indoors. In the work on Agenda 2 1, which is taking place in all municipalities in Sweden, health aspects should be given prominence as an expression of a holistic approach to human beings. Material for this has been submitted in the report of the government Commission on Environmental Health (SOU 1996: 124).

Ecological construction forms part of the change in Sweden towards a society that is sustainable in the long term, with provision for recycling and more effective use of energy as its goals. The structural solutions vary, and it is assumed that the health advantages for those who live and work in these buildings are a natural consequence of interest in the environment. Experiences and descriptions of health effects have not yet been compiled. Health impact assessments in conjunction with ecological construction should therefore be recommended.

2. Characteristics of healthy schools

As part of the work within the ISIAQ group on school environments, there have been discussions on what it is that characterises a school building with a good indoor climate. Characterisation of a healthy school building is a good basis in setting up goals and specifying requirements for the indoor climate. A client who does not define his wishes regarding the indoor climate cannot expect to have these wishes satisfied. Specific performance requirements for a good indoor climate in schools may look different depending on the aspirations of the client, but they also vary from country to country. The starting points are different owing to differences in occupancy rates, building traditions, outdoor climate etc. We have therefore decided in this context to describe the general characteristics of a healthy school in a Nordic climate.

2 1 Characteristics of healthy environments in schools

The environment in school should not initiate or provoke any diseases or accidents. Allergy and other hypersensitivities are the most common diseases among children and young people in the western industrialised world. It is therefore necessary to look upon the environment in schools from an allergy point of view to prevent pupils being sensitised ('primary prevention) and to minimise problems for pupils who are already affected (sensitised). (Secondary and tertiary prevention).

One basic function of a school is to provide stimulating and productive educational environments for the learning process[1].At least three different pedagogic settings which are difficult to combine in the same room may require different environmental solutions regarding acoustics, lighting, etc. These are the **classroom** (for teaching, lectures, teacher-class dialogue), the **silent room** (for individual concentration, e.g. a library) and the **group room.** A separate place to eat may also be needed.

2.2 Requirements

1. **Tobacco** (Environmental tobacco smoke, ETS). Children have the right to ETS-free environments. Exposure to ETS should be minimised. Tobacco smoking should be prohibited

in schools - both indoors and outdoors! (Already implemented in Sweden, Finland, Norway and other countries). One problem is how to define non-exposure level.

Cleaning to prevent accumulation of dust and other pollutants. The educational context in school must be taken into consideration. The requirements depend on needs defined by occupancy rates and activities and must comprise all surfaces exposed to indoor air. They include regular cleaning, periodical thorough cleaning and washing of fabrics and curtains. Furnishings and surfaces should make it possible for cleaning of advanced standard to be carried out. Cleaning should be performed using environmentally friendly methods and chemicals. The Clean Building Philosophy must be incorporated into the construction process[2].

Maintenance has to be adequate according to the needs of the specific building.

Carpets are a potential source of allergy. In order to minimise exposure to allergens and bioaerosols, fitted carpets should not be used in classrooms and other premises where children are present. Acoustic problems can be solved without creating new sources of pollution (MMMF, rockwool and fibreglass dust).

Allergens - pets, furry animals. Animals should not be allowed to enter schools. Special precautions must be taken if a guide dog is needed.

In order to avoid high levels of allergens being transported in clothes from home and outdoor environments, there may be a need for routines for cleaning clothes, ventilated wardrobes, special school uniforms, use of indoor shoes, etc.

Ventilation with fresh air is needed for good indoor air quality, to avoid moisture damage and to reduce infections, allergy problems and SBS symptoms. Investigations are needed concerning the influence of ventilation on the transmission of colds and flu.

Methods

l Methods for the operation and maintenance of schools

ice addressed to the different players who influence the operation and maintenance of heating, ilation etc installations in schools was included in the material produced during Allergy Year This advice is also geared to different stages in the life cycle of a school. It is often faults which :asy to put right that cause an unnecessary deterioration in the indoor climate. Well functioning ation is not only a health issue but also lays the foundations for effective energy use.

ı for operation and maintenance - advice for designers and clients

:ther operation and maintenance will function well in a long term perspective is decided as early uring the planning of new construction or renovation. Important decisions are made in the early es. Who can or wants to look after a building which has constricted service rooms and/or cult transport routes, or has no sampling points for check measurements on heating and ilation?

fly, the advice developed in the handbook is as follows:

Put operational and maintenance issues on the agenda already at the programme stage and call operational staff to planning meetings.

Budget for easy to understand operational and maintenance instructions which are drawn up for the building in question.

Appoint the person responsible for operation and maintenance at an early stage.

Make provision for continuous inspection. During the procurement process, refer to prepared models of operational and maintenance instructions.
Be well informed about codes and applicable legislation.

Allow time for the commissioning of the building - advice for clients, contractors and designers

Faults or shortcomings always occur during the design and construction stages. These may often be difficult to detect and may give rise to high operating costs. It is therefore important to make proper provision for the commissioning of the building, i.e. to test all systems and adjust these until they work as intended and the faults have been put right.

Briefly, the advice developed in the handbook is as follows:

Budget for commissioning.
The person in charge of design should be responsibe for commissioning during the entire construction process.
Ensure that commissioning is included in the programme documents.
Draw up a plan for commissioning. Make provision for control functions.
Draw up clear descriptions of different system solutions and how they must be tested.
Make specially careful observations of climate, technology and energy use during the first two years. Plan for follow-up questionnaires and measurements.

How to carry out operation and maintenance for a good indoor environment - advice for operational staff

Briefly, the advice developed in the handbook is as follows:

Make sure that complete, easy to understand operating and maintenance instructions, drawn up for the building in question, are available. Test them and ask questions.
Check the climate in the school regularly in conjunction with the annual safety inspection. Use questionnaires and measurements. Talk to the users.
Set up clear signs in the plant room for the different components of the heating and ventilation installation. Also put up signs in the premises to show when the ventilation was last checked and how many people the room is intended for.

2.3.2 Methods for healthy renovation of schools

Advice on how indoor climate issues can be monitored when a school is renovated has been compiled in a special programme. This was produced by the National Institute of Public Health for Allergy Year 95 in cooperation between indoor environment researchers, physicians and building practitioners. The programme has since been subjected to broader scrutiny by professionals in different areas. Much in this programme is also applicable for new construction and for buildings other than schools. Briefly, the six fundamental methodological steps recommended and developed in the programme are as follows:

1. *Form a renovation group of broad competence.*
   Instruct the group to collect the most recent research findings concerning the indoor environment.
2. *Draw up a situation report on the existing indoor environment in the school.*
   Using a questionnaire, investigate air quality, thermal environment, acoustics and lighting. One aid that is available is a school questionnaire on indoor environment and health. Make technical measurements of moisture states and air flow rates if the questionnaire indicates defects. What is worth preserving and what needs to be improved?
3. *Formulate goals for the indoor environment.*

Do this in the form of performance requirements, i.e. in terms that can be checked and in terms of **requirements concerning the properties of the building -** not in terms of the technical solutions. An aid gives examples of how checkable goals can be formulated.

4. *Apply quality assurance.*
   Specify performance requirements for building materials, system solutions, structures, workmanship and working methods on the site (dry and clean site, materials control, etc). The performance requirements must be commensurate with the goals set up in Item 3. An aid gives examples of what a checklist for quality assurance may look like.
5. *Make observations of indoor climate in the finished building.*
   Check the attainment of the goals using a questionnaire. Allow time for commissioning and experience feedback.
6. *Make observations of indoor climate during school hours.*
   This can be done using a standard questionnaire. In order to pay special attention to the situation of allergic persons, an allergy inspection can be made. This is described in detail at the end of this article as an example of the aids which the programme contains. Finally, the importance of careful operation and maintenance is emphasised - one of the ways of ensuring this is to train staff.

2.3.3 Methods of surveying school buildings with indoor climate problems, and remedial remedial measures

Advice on how school buildings can be surveyed in stages and how problems can be put right were summarised in an easy to read book published by the National Institute of Public Health and the Association of Swedish Local Authorities in 1996. The book came into being as a result of interviews by a journalist with a number of researchers, physicians and people responsible for real estate in some municipalities with experience of sick buildings.

This method book is also divided into six main stages for remedial measures. Briefly, the six methodological stages recommended and developed in the book are as follows:

1. *Make simple checks - lis ten to those who work in the premises.*
   Take remedial measures if the causes can be established. Follow up the effects of these measures. If this is not enough,
2. *Make an initial inspection of the building.*
   As the basis for the inspection, the building owner provides documents which describe how the building is intended to function. Any deviations are to be noted during the inspection. Take remedial measures if the causes can be established. Follow up the effects of these measures. If this is not enough,
3. *Make a standardised questionnaire survey or interview the users.*
   Collate the results and analyse which environmental and health factors annoy the users. Take remedial measures if the causes can be established. Follow up the effects of these measures. If this is not enough,
4. *Continue investigations in the building.*
   Check the structure and the building services (moisture, odours, heating, acoustics, lighting), the use of the premises, cleaning, "environmental culprits" and individual factors Take remedial measures if the causes can be established. Follow up the effects of these measures. If this is not enough,
5. *Make in-depth measurements depending on how well the causes have been located.*
   Air flow rates, chemical reactions/alkalinity, microorganisms, thermal environment, acoustics and lighting. Take remedial measures if the causes can be established. Follow up the effects of these measures. If this is not enough,
6. *Medically examine the users and make targeted measurements.*

Great attention is paid in the book to the interaction between the different players during the various stages. The situations which arise when the health of pupils and staff in a school is at stake are very sensitive. It is emphasised that the building owner should listen to the views of the users and should work systematically and in stages, with each stage firmly tied to the previous ones.

2.4 Examples of aids - Allergy Inspection

The checklist for the allergy inspection is a working tool for the identification of allergy risks in the indoor environment.

The allergy inspection is a safety inspection with allergy as its theme, and should be made by those who normally deal with environmental issues in the school. Those taking part in the allergy inspection should be, in the first place, the headmaster, safety officer, pupils' safety representative/parents' representative and school nurse. The person responsible for the building should attend to issues concerning indoor climate and ventilation, the person responsible for meals to issues concerning food, and staff responsible for cleaning to issues concerning cleaning.

The completed checklist will then form the basis for a plan of action for remedial work. In most cases, some measures can be taken quickly at low cost, others require a longer tertn approach. It is important that 'attitude' issues such as those concerning smoking, furry animals and perfume should be kept under continual review and highlighted.

It is not necessary to be an expert in allergy issues to make an allergy inspection, it is a learning process. The checklist is an aid in quickly and easily obtaining an overview of where allergy risks are to be found and which factors in the environment or the activity should be put right. Examples of issues which are examined are:

Health issues
Indoor climate
Ventilation
smoking
Furry animals
Perfumes
Plants
Food
Facilities management

The checklist is a good aid to use in the annual safety inspection. It focuses on the indoor climate for allergic children and at the same time calls attention to a healthy environment for all children.

M. Kjellman, Jan Sundell, The air we breathe indoors, National Institute of Public Health, Sweden, 1994: 16.

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1 Rydén, E, Ed. Bygga Hälsa i Norden. (Building health in the Nordic countries). (In Swedish). Boverket, Karlskrona, Sweden, 1977. An abbreviated report is available in English.

2 Wessel Johnsen, L.G. The Clean Building Concept - Working Methods. In: Woods J E, Grimsrud D T, Boschi N, Eds, Healthy Buildings/IAQ '97. Washington DC 1997. Vol. 2, pp. 341-346.

ADSORPTION OF AIR CONTAMINANTS ON INDOOR SURFACES

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Abstract

The process of sorption of air contaminants and the subsequent desorption may have important consequences for the indoor air quality. For example, occasional release of consumer chemicals leads to momentarily high concentrations in the room air, which in turn results in a strong sorption on material surfaces. This paper treats the methodology and development of an experimental equipment for investigating how volatile organic compounds are sorbed on material surfaces. A mathematical model which incorporates mass transfer from bulk air to surface, surface adsorption, diffusion into the material and absorption is proposed. It is possible to evaluate four physical parameters when adapting the model to measurement data. The paper presents sorption experiments of toluene on three materials; stainless steel, wood particle board and gypsum board. The result shows that toluene is sorbed to a higher extent on a gypsum board than on a wood particle board. Gypsum board and wood particle board are permeable for toluene, while stainless steel is not. The proposed measurement technique seems to be applicable for determination of such material parameters which are necessary for predicting the indoor air quality in a real environment.

Keywords: Adsorption, Building materials, IAQ, Sinks, VOC

1 Introduction

Due to indoor contamination sources of different kinds, the indoor air is as a rule more polluted than the ambient air. The sources of contaminants are broadly speaking all materials which we have indoors, building materials, fittings, furnishings, consumer products etc. Not least are we - the occupants, with all our activities - major contributors to the contamination. Cleaning, cooking, painting, gluing, using deodorants and perfumes and other body care products all have a negative effect. Lastly the biological metabolism itself makes contributions which should be eliminated.

The main purpose of ventilation is to remove contaminants from the indoor environment. The classical way is to treat ventilation as a dilution process. The level of air contamination is then modelled by a simple differential equation, which states that the amount of pollutant accumulated in the room air is the difference between what is supplied from the sources (the emission rate) and what is extracted along with the ventilation air.

However, over the past few years it has become obvious that other processes play an important part in the level of contamination. Specifically, all material surfaces in the room interact with the air contaminants in an exchange process. Such interactions may have a large impact on the human exposure to air contaminants. Occasional release of consumer chemicals leads to momentarily high concentrations in the room air, which in turn results in a strong "sorption" on material surfaces. Later, the sorbed compounds may slowly migrate back to the room air, yielding an extended exposure time. Repeated use of consumer chemicals can build up considerable depots of contaminants in indoor materials.

Only a small part of the compounds in indoor air comes from this secondary emission from such depots. The main part is generated directly from the primary sources. However, people often avoid exposure to much of the primary emissions by leaving the room for example. When painting, it is common to leave the room while waiting for the paint to dry. The odour is often a signal to avoid primary emission, - a factor which is normally not present during secondary emission, due to the relatively low concentration. As chemicals are often released repeatedly in the indoor environment, there will be a build up of compounds in the depots. This may cause the subsequent re-emission from depots to be greater than the emission from primary sources, such as building materials, which decays after some time in a new building.

It should be clearly stated that the depot effect is not the major contributor to the average levels of contaminants in indoor air, but it may be of significance due to prolonged low level exposure for humans.

In order to find the most effective ways of protecting people from adverse exposure to indoor contaminants, it is essential to be able to predict what happens when chemicals are brought inside. Knowledge of source emission rates and ventilation characteristics are essential for predicting indoor air quality, but to complete the picture, the adsorption and desorption characteristics of different contaminants on different materials must also be known.

The mathematical model of the processes should be formulated in terms of physical interpretable parameters, such as diffusion coefficients and equilibrium constants and it should be of general validity.

The aim of this work is to develop an experimental methodology, with which such material parameters, necessary to describe the sorption/desorption process, can be determined.

2 Mechanism of the sorption process and a simple mathematical model.

The sorption process of contaminants on a solid material can be looked upon as seriallv coupled sub-processes consisting of:

1. Diffusion from bulk air through the boundary layer near the surface
2. Surface adsorption
3. Diffusion into the material
4. Absorption in the interior of the material

For simplicity all processes are considered reversible so the re-emission follows the reverse process.

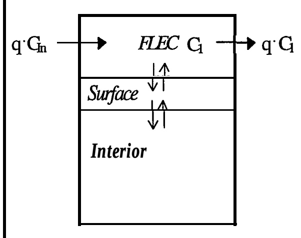

Figure 1. The sorption process.

Simple mathematical models can be set up for each of these sub-processes. Numerical solution of the system of simultaneous differential equations can be compared with experiments in order to determine the model parameters.

2.1 Governing equations

2.1.1 Diffusion through the boundary layer:
The mass transfer rate of the gaseous compound from the bulk air phase to the surface is described by a mass transfer coefficient k_g so that

$$J_1=Ak_g(c_a-c_s) \quad \textbf{(1)}$$

where c_a is the concentration in the air phase and c_s is the gas phase concentration of the compound at the surface interface.

2.1.2 Adsorption on the surface: This process is considered so fast that the gas phase concentration at the surface interface c_s is always equal to the gas phase concentration of the compound in equilibrium with the surface.

Thus, c_s is determined by the equilibrium constant, K_s, for the surface adsorbed compound.

$$K_s = \frac{c_s}{C_s} \quad \textbf{(2)}$$

where C_s is the concentration of adsorbed compound on the surface. This equation corresponds to a so called linear adsorption isotherm. The linear relation was demonstrated by Tichenor [1] in similar experiments.

2.1.3 Diffusion into the interior of the material.

This process is considered a pure diffusion process and is not normally covered in already existing models in ref. [1],[2]and [3]. The compound balance equation in one dimension for a porous media can be formulated as:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(g) \quad \textbf{(3)}$$

where C is the total concentration of the compound inside the material, xis the distance from the surface and g is the compound flux caused by diffusion:

$$g = -D\frac{\partial c}{\partial x} \quad \textbf{(4)}$$

where D is the molecular diffusion coefficient and c is a fictitious gas phase concentration (or activity), in the material.

c_i is determined by the equilibrium constant, K_i , between the vapour and the total concentration of compound.

$$K_i = \frac{c_i}{C_i} \quad \textbf{(5)}$$

Equation 3 can now be written as;

$$\frac{\partial c}{\partial t} = D \cdot K_i \frac{\partial^2 c}{\partial x^2} \quad \textbf{(6)}$$

2.2 Adapting of the model

Assuming numerical values of the four parameters (k_g K_s D and K_i), the system of equations together with the boundary conditions can be numerically solved using a finite difference technique. Comparing the result with experiments allows the parameters to be adjusted to yield a best fit between the numerical solution and the experimental data. Figure 2 shows an example of such a fit.

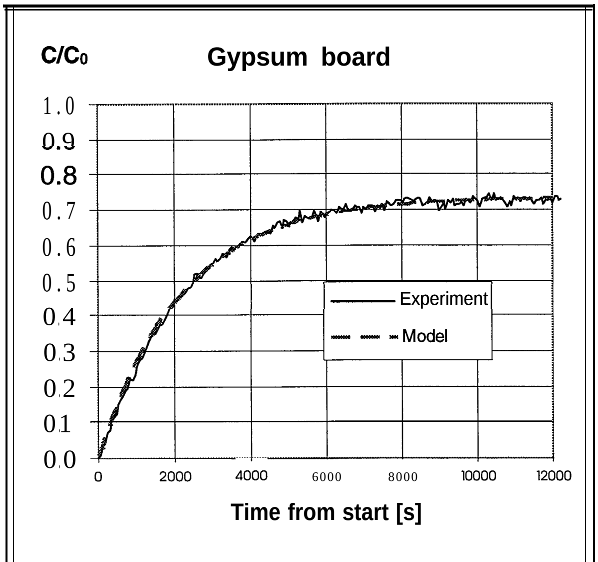

Figure 2. *Adaptation of model parameters to experimental data. c/c_0 (chamber outlet concentration / 'nlet concentration) versus time.*

The experiment was performed according to the procedure described in the experimental section of this paper. In essence a step change of the inlet concentration (from zero to c_0) of a contaminant in the air ventilating the space above a solid material is performed.

Figure 2 displays the experimental and modelled relative chamber concentration for gypsum board when subjected to 100 ml/min of dry air with an inlet toluene concentration of 10 mg/m^3.

3 Experimental study

This section describes the experimental methodology and equipment. The aim of the study is to further develop and test an experimental technique, with which the material parameters in a general adsorption model can be determined. The objective being to develop a convenient small scale technique, yielding sufficient data necessary for modelling behaviour in full scale reality.

3.1 Experimental method

In this pre-study we have focused on the adsorption process. Of course this is just one part of the depot phenomenon and in the near future the desorption process will also be evaluated. The methodology used in these experiments involves exposing a test material placed in a small climate chamber to a volatile organic compound (VOC). Toluene was chosen as a model compound in this case. By studying the concentration in the outlet as a function of time after a step change in the inlet concentration, it is possible to examine the adsorption/absorption properties.

3.2 Climate chamber

The FLEC (Field and Laboratory Emission Cell) was used in these experiments. The FLEC was originally designed for analysis of emissions of VOCs from building materials. The equipment mainly consists of a circular cover made of stainless steel, with an inner geometry which provides a uniform air velocity over the test sample [4]. It is placed on top of the test material, so that the test material forms the bottom of the apparatus. The enclosed volume is 35 cm^3 and the exposed area of the test specimen is 0.0177 m^2 , which gives a maximum loading factor of 506 m^2/m^3. The surface to volume loading factor of the FLEC is therefore nearly 300 times that of an ordinary room. Only one side of the material is exposed to the compound as in a real room.

3.3 Climate control

In order to provide a controlled temperature during the tests, the test specimen was supported from below by a 30 mm thick thermostated aluminium plate, through which thermostated water was circulated in a 5 mm wide channel in the form of a labyrinth. This equipment together with a hood of polystyrene (10 cm thick), insulating the FLEC, test material and the thermostated plate, were sufficient to control the temperature for the experiments.

3.4 Sealing method

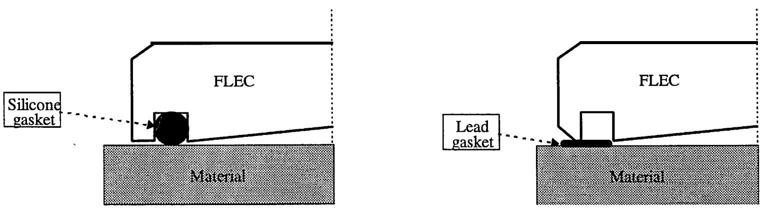

Figure *3. The outside perimeter of the FLEC with its original gasket which acts as a sink for toluene (left). Sharpened perimeter and new gasket (right). The sharpening leads to increased pressure on the lead gasket (for deformation).*

The sealing of the FLEC to the test material is of great importance in these experiments. Factors influenced by the type of seal are: air flow rate and air velocity as well as the adsorption and desorption rate. At the start of this project it was discovered that the original O-ring seal, made of silicone rubber, acted as a severe depot and leak for toluene vapour. For this reason a new seal was designed. Several attempts were made in order to fulfil the requirements of tightness, impermeability and non-sorbing characteristics towards toluene. The latest successful version is shown in figure 3 in which the FLEC was sharpened on the outside perimeter to provide enough pressure on the seal. The seal was manufactured from a lead foil (1.5 mm thick). The metal is impermeable to toluene and has negligible adsorption. Each experiment requires a new seal because of the deformation when the FLEC is fixed to the test material. The pressure for deformation was organised by six stainless steel clamps threaded into the aluminium plate.

3.5 Air generation

The compressed air system at the laboratory is of good quality, dry (RH< 5 %) and with low particulate content. However, to reduce the amount of VOCs originating from the compressor oil a gas-clean charcoal filter is used. The filter manages to keep the VOC-level below 1 ppm for one year. For safety reasons, if the internal dryer of the compressed air system should break down or malfunction, a gas-clean moisture filter is used. Both filters are of a type normally found in gas chromatography applications. Additionally, for protection of valves and the analysis equipment, a Nupro ”F series” particle filter is used which traps particles of diameters down to 0.5 microns.

3.6 Compound

Toluene was chosen as the model substance because it is a common contaminant in the air having consequences for health. The average concentrations of toluene in room air are 80 $\mu g/m^3$ and 5 $\mu g/m^3$ in ambient air [5]. It is a common solvent and is found for example in detergents, cleaning agents, glues and paints. Occurrence of toluene is of health concern because it can irritate the mucous membranes. Jorgensen [6] has reviewed results from four investigations of screenings of compounds in the indoor air of buildings (mainly dwellings) in Denmark, Italy, Germany and USA. This was done in order to choose relevant compounds for experiments similar to the present ones. Two compounds from 21 examined were chosen by her, a-pinen and toluene. Toluene was chosen because of its irritating effect and its occurrence rate.

3.7 Compound generation

Air with a fixed concentration of toluene was prepared by letting a constant flow of the purified air pass a constant source of toluene vapour. The source (fig. 4) consists of a container of aluminium in which a wick of fibre glass is placed. At the open end of the container a glass capillary tube is fixed to the container wall with a solvent free epoxy resin. The resin is not permeable to toluene. Before using the sources, liquid toluene is injected with a syringe through the capillary tube into the wick. Because of the fact that the vapour pressure is strongly dependent on temperature, the source is kept at a constant temperature of 20 °C. Toluene vapour is emitted at a constant rate controlled by diffusion through the capillary tube the dimensions of the glass tube (diameter and height) governing the emission rate. Calibration of the emission rate is performed by weighing the sources with an accurate balance. The emission rate of the sources used in these experiments is 50 ng/s.

3.8 Compound compartment

In the compound generator compartment the compound emitted from the source is mixed with air to the desired concentration. As for the FLEC it was important to minimise adsorption and eliminate leakage and diffusion out of the compartment. The generator compartment therefore only contains metal and consists of an U-shaped copper tube, equipped with brass fittings mounted with compressor couplings. The tracer sources are placed in the vertical part of the compartment near the air inlet. The compound compartment with its content is immersed in a water circulator which maintains a constant temperature of 20 °C.

3.9 Flow chart and flow control

The flow of air in the experiments is illustrated in a flow chart in figure 5. The compressed and filtered air is divided into two paths: for contaminated and clean air respectively. The former is contaminated in the compound compartment and distributed to a switch valve where it either flows into the FLEC or out into the lab (flush). Between the compound compartment and the switch valve there is an additional branch pipe were one part of the air is continuously bypassed for control measurement of the desired concentration. The clean air flows directly to a switch valve where it either enters the FLEC or travels out into the lab (flush). Adsorption experiments start by flushing the FLEC with clean air (switch valves are positioned so that clean air flows into the FLEC and contaminated air flows out into the lab, path A in figure 5). When the FLEC is to be exposed to the compound, the switch valves are positioned in the other direction so that contaminated air flows into the FLEC and clean air flows out into the lab. The air flow through the compound compartment and FLEC is controlled by precise stainless steel needle valves. Flow measurements are performed with a digital soap film flow meter which requires a negligible pressure drop. This is essential since there is a slight over-pressure in the FLEC and any increase of this may influence the air flow through it.

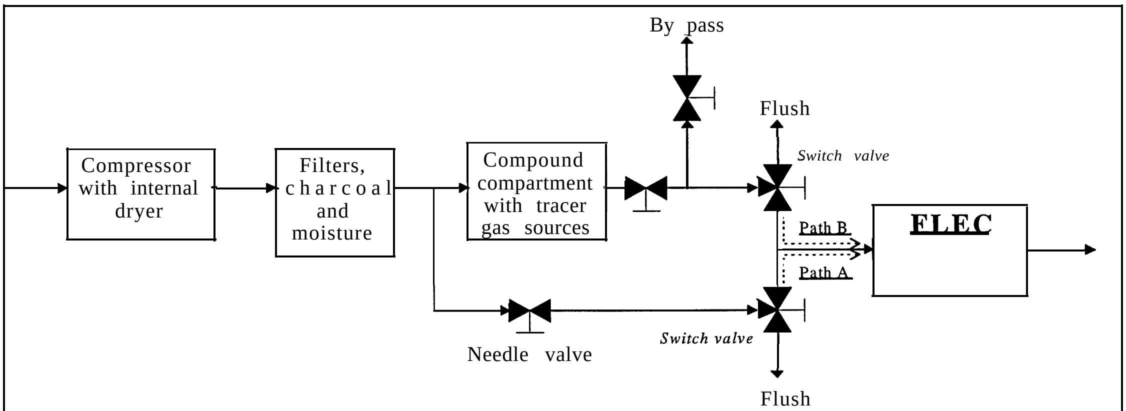

Figure *5. Flow chart of the experimental set-up. Before the step change in contaminant concentration the clean air flows through the FLEC (path A) and the contaminated air is flushed out into the lab. At the start of an adsorption experiment contaminated air is allowed to enter the FLEC (path B). When a steady state concentration is established in the FLEC outlet, path B is changed for path A. Switching between clean and contaminated air is managed by simultaneous operation of the two switch valves*

3.10 Concentration measurement method

The concentration of toluene in air was measured with a Balzers quadrupol mass spectrometer (MS). Other analysis techniques exist which could have been used: gas chromatography or IR-spectroscopy. The fast sampling interval and the presentation of data in real-time are the main advantages of MS. One disadvantage however is the poor detection limit, 0.2-0.5 ppm. A personal computer together with the software "QUADSTAR 421" from Balzers makes it easy to control the mass spectrometer and follow the concentration of the compound in real time.

3.11 Test material

The materials examined in this work were: gypsum board and wood particle board. The chosen building materials are often used in building construction. Additionally, a stainless steel plate was used for tests where the internal depots of the experimental apparatus were to be examined. The test materials had been stored for one to several years in the laboratory workshop (20 - 25 °C and RH = 30 -50 % approx.) before the experiments.

3.12 Experimental conditions

The stainless steel, gypsum board and wood particle board were subjected to adsorption tests to evaluate the different adsorption characteristics of each material. The following parameters were kept constant during the measurements: Temperature 20±0.5 °C. Air flow rate = 100 ml/m^3, corresponding to an air velocity of 0.35 cm/s. Inlet concentration of toluene: 10 mg/m^3.

4 Results and discussion

The result from the step change in concentration for the three materials is displayed in figure 6. It is evident that the materials exhibit widely different sorption characteristics. As can be seen, the SS-plate (stainless steel) is quickly saturated at the surface with toluene. This is a consequence of the non-permeability of this material.

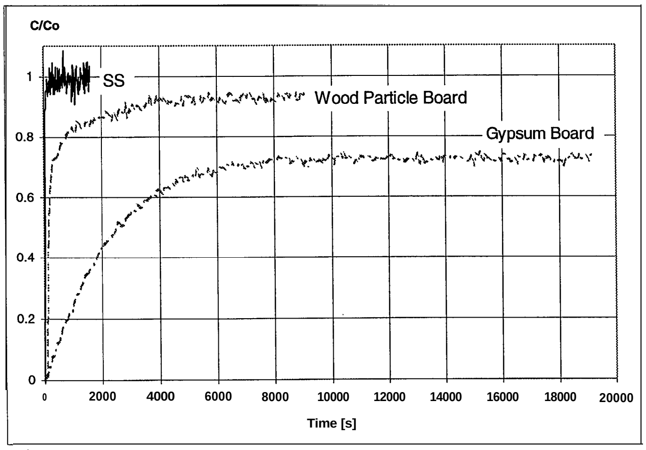

Figure 6. *Outlet concentration C / inlet concentration C_o of FLEC as a function of time for adsorption experiments. The materials were subject to identical experimental conditions*

Wood particle board (WPB) shows a moderately fast build up of toluene on the surface initially, (up to c/c_0=0.7) and a subsequent continuous transport of toluene into the material. The rate determining process in the latter sorption phase is internal diffusion. According to figure 6 gypsum board (GB) is a powerful depot for toluene. The surface of GB can accumulate appreciably more toluene compared with the other materials and the initial concentration step up is the slowest. As for WPB diffusion into the material is the rate determining process for GB after the initial step up. The experiments show that GB has the highest toluene permeability and diffusion coefficient followed by WPB. SS is non permeable for toluene. Furthermore, after the initial concentration step up one can see that only SS reaches the inlet concentration in the outlet. The other two materials approach an apparently constant sink rate. An explanation for this phenomenon may be that the solubility of toluene in WPB and GB is so large that equilibrium is far from being approached during the measurement time. This would show up as a quasi-steady-state, similar to predicted results for an irreversible sink. Another explanation could be diffusion from the interior to the edges of the material, (only one side of the material is exposed in the FLEC).

5 Acknowledgements

The authors would like to thank Mr. Erik Borgh, University College of Gävle Sandviken who completed his diploma work within this project. He participated in the development of the experimental apparatus and contributed with experimental work.

6 References

1 Tichenor, B.A., Guo, Z., Dunn, J.E., Sparks, L.E. and Mason, M.A.“The interaction of vapour phase organic compounds with indoor sinks” *Journal of Indoor Air* Vol. 1 pp **23-35, 1991.**
2 Axley, J.W “ Adsorption modelling for building contaminant dispersal analysis” *Journal of Indoor Air,* Vol. 2, pp 147 - 17 1, 1991.
3 Dunn, J.E. and Tichenor, B.A. “Compensating for sink effects in emissions test chambers by mathematical modelling” *Atmospheric Environment”* Vol. 22, No 5. pp 885 - 894, 1988.
4 Wolkoff, P., Claussen, P.A., Nielsen, P.A., Gustafsson, H., Jonsson, B. and Rasmusen, E. “Field and Laboratory Emission Cell: FLEC” *American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc.: IAQ ‘91, Healthy Buildings Washington D. C.,* pp 160- 164, 199 1.
5 Maroni, M., Seifert, B. and Lindvall, T. ” *Indoor air quality -a comprehensive reference book”* Elsevier science B .V., Amsterdam, 1995.
6 Jorgensen, R.B. ”*Materialoverfladers indflydelse på luftkvaliteten*” Danmarks Tekniske Höjskole, Diploma work (in Danish), 1992.

Egg tempera or water based paint?
An epidemiological study.

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Abstract
Some recent investigations have shown an increased prevalence of asthma and sick building syndrome (SBS) in newly painted buildings. Water based paints (WBP) are used in 95% of indoor painting in Sweden. New types of WBP with improved polymers, making it possible to further reduce the concentration of volatile organic compounds (VOC) in the paints, have been marketed during the 90'ies. There is also a growing interest in older types of paints, based on linoleic oil, in combination with egg or casein protein. The aim of the study was to compare asthmatic symptoms and SBS in two office buildings in the city of Uppsala, both redecorated in 1995. One building was painted with a paint based on linoleic oil and egg (egg-tempera), the other was painted with a new type of WBP low in VOCs. Both buildings had mechanical supply/exhaust air ventilation and linoleum floors. A self-administered questionnaire was distributed to all employees in March 1997. Indoor measurements of VOCs, moulds, bacteria, formaldehyde, respirable dust, CO, CO_2, NO_2, and ozone were performed in both buildings in April 1997. Statistical analysis was performed by multiple logistic regression, adjusting for possible influence of age, gender, tobacco smoking, and atopy. The indoor concentration of pollutants was low in both buildings. The prevalence of facial skin symptoms (rash or itch) was increased in the building painted with egg-tempera. No significant difference of asthmatic symptoms (wheeze or attacks of breathlessness), eye symptoms, nasal or throat symptoms, or general symptoms such as headache, fatigue or nausea was observed between the buildings. The prevalence of doctors' diagnosed asthma was 9% in both buildings. One new case of doctor's diagnosed asthma occurred in the population in egg-tempera building (N=177) after the redecoration in 1995, no new case of doctor's diagnosed asthma occurred after the redecoration in the WBP building (N=56). Perceived air quality did not differ significantly between the two buildings. In conclusion, the use of egg-tempera paint indoors, claimed to be beneficial from an "ecological" point of view, does not seem to represent any health-related improvements of the indoor environment, as compared to the new type of water based paints, low in VOCs.
Key words: asthma, egg tempera, water based paint, sick building syndrome, microbial volatile organic compounds (MVOC)

Introduction

Concern has increased about possible health effects and discomforts resulting from indoor air pollution. Disorders that have been associated with indoor air pollution include asthma, allergies, and nonspecific irritative symptoms from eyes, upper airways, and facial skin. These nonspecific symptoms are sometimes referred to as the sick building syndrome (SBS). Several epidemiological studies on such symptoms have been published, identifying possible factors related to SBS (1-4), building-related asthmatic symptoms (1), and subjective indoor air quality (1). In addition, SBS, asthmatic symptoms and the perception of indoor air quality may also be influenced by personal factors, such as female gender, tobacco smoking, psycho-social work conditions, and allergic disorders (l-4)

Volatile organic compounds (VOC), formaldehyde, and airborne aerosols have been related to health effects and building related complaints in some studies (l-4). One common source of indoor VOCs is emissions from fresh paint (5-S). Two recent studies have shown that 26-32% of the Swedish population have had the interior of their dwelling painted during the last year (5-6). There are also some indications that emissions from fresh indoor paint may increase the occurrence of upper airway symptoms (5,8), eye irritation (6,8), and asthma (6,7).

The chemical composition of indoor paints has changed drastically during the last decades. Earlier, solvent-based paints were commonly used for indoor painting in Scandinavia, nowadays about 95% of indoor paint in Sweden is water based paints (WBP) (9). The shift from solvent-based paint to water-based paint has reduced the total emission of VOCs from indoor paint, but shifted the exposure toward new types of more polar and high boiling VOCs (10). Further changes of indoor paints have taken place the last years in Sweden. New types of WBP with improved polymers, making it possible to further reduce the concentration of volatile organic compounds (VOC) in the paints, have been marketed during the 90'ies. There is also a growing interest in older types of paints, based on linoleic oil, in combination with egg or casein protein. There is, however, scarce information in the literature on how these new paints affects the indoor environment, or the inhabitants of the newly painted buildings.

Because of the lack of epidemiological studies in this field, we have performed a study on asthma, SBS, and subjective indoor air quality in two office buildings in the city of Uppsala, both redecorated in 1995. One building was painted with a paint based on linoleic oil and egg (egg-tempera), the other was painted' with a new type of WBP low in VOCs.

Material and methods

Study population and type of buildings

Both buildings were office buildings and situated 1 km from each other, in the central parts of Uppsala, a mid-Swedish municipality with about 160 000 inhabitants. The first building was an older three-storey building with the social welfare administration. It had 219 employees, and was redecorated in 1995 with a new type of water based paint, low in VOCs. The second building was an older seven-storey building with 66 employees, containing the administrative unit for the university of Uppsala. It was also redecorated in 1995, but with a paint based on linoleic oil and egg (egg-tempera). Both buildings had mechanical supply/exhaust air ventilation and linoleum floors.

Assessment of symptoms

A self-administered postal questionnaire was distributed to all employees in March 1997, off pollen season. It contained questions on personal factors such as age, sex, smoking habits, occupation, asthma, allergies, and atopy. It also contained some questions on the home environment, including building age, house pets, number of members of the family, indoor painting, presence of wall-to-wall carpets, and signs of building dampness in the dwelling.

Questions on asthma included one question on doctor's diagnosed asthma, and year of diagnosis. In addition, there were three questions on asthmatic symptoms during the last 12 months (wheeze or daytime/nighttime attacks of breathlessness), previously used in the worldwide European Community Respiratory Health Survey (ECRHS)(11).

Information on 23 symptoms compatible with the sick building syndrome was obtained from a self-administered questionnaire. The recall period was seven days. For each symptom, an answer could be given according to two options; "no" or "yes" . The symptoms were classified as: eye symptoms, nasal symptoms, throat symptoms, facial skin symptoms, and general symptoms. In addition, a symptom core ranging from 0 to 23 was constructed, by summing up the number of "yes" answers.

Finally, the questionnaire contained three 10 cm analogue rating scales on different aspects on subjective indoor air quality. The first scale was a general scale on perceived air quality (O-l 00%), the second was on perceived air dryness (O-l 00%), and the third scale (0-100%) was dealing with the perception of dustiness of the air.

Assessment of exposure

Indoor measurements of VOCs, moulds, bacteria, formaldehyde, respirable dust, CO, C02, N02, and ozone were performed in both buildings in mid-April 1997. Measurements with direct reading instruments, and pumped air sampling, were made on two different days in each building. In addition, ozone, carbon monoxide, carbon dioxide, and nitrogen dioxide was measured by diffusion sampling, for seven days. Ozone, respirable dust, and VOCs were also measured in the outdoor air, outside the buildings.

Room temperature and air humidity were recorded with an Assman psychrometer. Concentrations of respirable dust were measured by a direct reading instrument based on light scattering (Sibata P-5H2, Sibata Scientific Technology Ltd, Japan). The instrument was calibrated by the manufacturer to 0.3 µm particles of stearic acid. Indoor CO2 concentration was measured by a direct reading infrared spectrometer (Rieken RI-41 1 A, Rieken Keini, Japan), calibrated by standard gases containing known concentrations of C02. Air borne microorganisms were sampled on a sterile 28 mm polycarbonate filter (Nucleopore, Millipore Corp., USA) with a pore size of 0.4 µm, the sampling rate being 2.4 L/min, for 6 hours. The total concentration of airborne microorganisms was determined by the CAMNEA method utilizing epifluorescence microscopy. Viable moulds and bacteria were determined by incubation on two different media. The detection limits of viable microorganisms were 50 colony forming units (cfu)/m^3 of air.

Indoor concentrations of formaldehyde were measured with glass fibre filters impregnated with 2,4-dinitro-phenylhydrazine, the air sampling rate being 0.20 L/min during six hours. The filters were analyzed by liquid chromatography. Volatile organic compounds were measured by sampling on both charcoal sorbent tubes (Anasorb 747) and synthetic polymer (XAD-7), followed by a gas chromatographical masspectrometric analysis (GC-MS). VOCs of possible microbial origin (MVOC) were sampled on Anasorb 747, desorbed with 1 ml methylene chloride, and analysed by GC-MC using selective ion monitoring (SIM) (12). The sampling time was 6 hours for both microorganisms, formaldehyde, VOCs, and MVOCs.

In addition, a qualitative analysis of VOCs in settled dust was performed. Settled dust was collected by drawing a glass fiber filter over the linoleum floor surface. Collected dust was desorbed by carbon disulphide, and analysed for VOCs with the same procedure as for the air samples.

Statistical analysis

The prevalence of symptoms in the two groups was compared with chi-2-analysis. The ratings of indoor air quality was compared by means od Student's t-test.Differences in exposures were tested by Mann-Whitney U-test. Multivariate statistical analysis was performed by multiple linear or logistic analysis with the SPIDA statistical package (the Statistical Laboratory, Macquarie University, Australia). Multiple logistic regression analysis was applied to study relationships between indoor environment and symptoms. Multiple linear regression analysis was used to study relationships between indoor environment, and the outcome from rating scales for subjective indoor air quality. Control was made for possible confounders: age, gender, smoking habits, and atopy. Adjusted odds ratios (OR), with a 95% confidence interval (CI) were calculated, adjusting for possible influence of age, gender, tobacco smoking, and atopy.

Results

Totally, there were 219 employees in the building painted with egg tempera (ET-building), 177 participated (8 1%). There were 66 employees in the building painted with water based paints (WBP-building), 56 participated (85%).

Personal factors

The distribution of personal factors was similar in the two groups. The mean age among the participants was 48 years in the ET-building, and 47 years in the WBP-building. The prevalence of females, current smokers and atopy was 73%, 18% and 3 1% respectively, in the ET-building. The corresponding figures were 88%,14%, and 30% in the WBP-building. None of these differences were statistically significant.

Measured indoor climate

Indoor climate was similar in the two buildings. Average room temperature was 22.9 ° C (21.5-24.0 °C) in the ET-building and 22.6°C (21.5-23.5 °C). Average relative air humidity was 23% (range 17-33%) in the ET-building, and 26% (range (17-37%) in the WBP-building. The average level of CO_2 was 580 ppm (500-700 ppm) in the ET-building, and 600 ppm (480-800 ppm) in the WBP-building.

Exposure measurements

Indoor concentration of NO_2 and CO, two traffic exhausts related pollutants, was significantly higher in the building painted with water based paint (Table 1). In contrast, the indoor concentration of volatile organic compounds of possible microbial origin (MVOC) was significantly higher in the building (Table 2). The outdoor concentration of MVOC did not differ between the two buildings. The average concentration of viable bacteria was 100 colony forming units (cfu)/m^3 in the ET-building and 140 cfu/m^3 in the WBP-building. The concentration of viable moulds was 50 cfu/m^3 in the ET-building, and 180 cfu/m^3 in the WBP-building.These differences were not statistically significant. Moreover, no significant differences in the concentration of total moulds or total bacteria were detected between the two buildings. Among viable moulds, *Penicillium* species were detected in the air both buildings, *Cladosporium* sp. were detected in the ET-building, only.

Table 1 Indoor and outdoor concentration of selected pollutants in the two buildings

Compound	ET-building M(min-max)	WBP-building M(min-max)
Indoor respirable dust (μg/m^3)	5 (4-7)	6 (5-8)
Indoor ozone (ppb)[a]	10.5(5.9-16)	16.7(7.1-37)
Outdoor ozone (ppb)	31	35
Indoor nitrogen dioxide (μg/m^3)	6(4-12)	14(12-18)**
Indoor carbon monoxide (ppm)	0.08(0.06-0.12)	0.15(0.12-0.18)*
Indoor formaldehyde (μg/m^3)	3.7(2-7)	4.5(4-6)

* $P<0.05$;** $P<0.01$ Significant difference between the two buildings by Mann-Whitney U-test

Table 2 Concentration of selected compounds of possible microbial origin (MVOC)

Type of compound	ET-building M(min-max)	WBP-building M(min-max)
Sum of indoor MVOC ($\mu g/m^3$)	0.38(0.26-0.42)	0.27(0.22-0.32)*
Sum of outdoor MVOC ($\mu g/m^3$)	0.04	0.08
Indoor 3 -methylfuran ($\mu g/m^3$)	0.02(0.016-0.02)	0.01(0.01-0.016)**
Outdoor 3-methylfuran ($\mu g/m^3$)	0.005	0.01
Indoor 1-octen-3-ol ($\mu g/m^3$)	0.07(0.04-0.10)	0.04(0.04-0.05)*
Outdoor 1 -octen-3-ol ($\mu g/m^3$)	0.003	0.02

* $P<0.05$;** $P<0.01$ Significant difference between the two buildings by Mann-Whitney U-test

Subjective indoor air quality

The perception of the indoor environment, and occurrence of medical symptoms was similar in the two buildings (Table 3).

Table 3 Subjective indoor air quality in the two buildings

	ET-building (M±SD)	WBP-building (M±SD)
Perceived air quality (0- 100%)	55±20	54±21
Perceived air humidity (0- 100%)	33±17	36±17
Perceived dustiness of the air (0-100%)	44±23	51±22

No significant differences between the two groups

SBS-symptoms

The prevalence of facial skin symptoms (rash or itch) was increased in the building painted with egg-tempera. No significant difference of asthmatic symptoms (wheeze or attacks of breathlessness), eye symptoms, nasal or throat symptoms, or general symptoms such as headache, fatigue or nausea was observed between the buildings.

Table 4 Subjective indoor air quality in the two buildings

Type of weekly symptoms	ET-building (%)	WBP-building (%)
At least one eye symptom	47	52
At least one nasal symptom	45	42
At least one throat symptom	39	43
At least one facial skin symptom	13	2**
At least one general symptom	67	71

** P<0.01 by chi-square test

Asthma and asthmatic symptoms

The 12 months' prevalence of asthmatic symptoms (wheeze or attacks of breathlessness) was 19% in the ET-building and 18% in the SBP-building, a non-significant difference. The prevalence of doctors' diagnosed asthma was 9% in both buildings. One new case of doctor's diagnosed asthma occurred in the population in egg-tempera building (N=177) after the redecoration in 1995, no new case of doctor's diagnosed asthma occurred after the redecoration in the WBP building (N=56).

Discussion

The design was cross-sectional and in such studies, selection effects may cause both underestimation and overestimation of the true relationship. Selection bias due to low response rate is less likely since the participation rate in the postal questionnaire was high (81-85%). The true adverse health effect of indoor painting could, however, been underestimated if there were a health based selection.

In conclusion, the use of egg-tempera paint indoors, claimed to be beneficial from an "ecological" point of view, does not seem to represent any health-related improvements of the indoor environment, as compared to the new type of water based paints, low in VOCs.

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References

1. Norbäck D. (1997) Indoor air quality, sick building syndrome (SBS), and specific building related illness. In: *The workplace. Vol.1 Fundamentals of Health, Safety and* Welfare, Scandinavian Science Publisher as, Oslo, pp. 501-32.

2. Mendell M.J.(1993) Non-specific symptoms in office workers: A review and summary of the epidemiological literature, *Indoor Air,* Vo13, pp. 227-36.

3. Apter A., Bracker A., Hodgson M., Sidman J., Leung W.Y. (1994). Epidemiology of the sick building syndrome, *J Allergy Clin Immunology,* Vol 94, pp. 277-88.

4. Hodgson M. (1995). The sick-building syndrome. *Occupational Medicine: State of Art Reviews,* Vol. 10, pp. 167-75.

5. Norbäck D., Edling C. (1991) Environmental, occupational and personal factors related to the prevalence of sick building syndrome in the general population. *Br J Ind Med*, Vol. 48, pp. 451-62.

6. Norbäck D., Edling C., Wieslander G. (1994) Asthma symptoms and the sick building syndrome (SBS) -the significance of microorganisms in the indoor environment. In: *Health implications of fungi in indoor environments,* Samson R.A., Flannigan B., Flannigan M.E., Verhoeff A.P., Adan O.C.G., Hoekstra E.S. (eds), Air Quality Monographs, vol 2, Elsevier, Amsterdam, pp. 229-39.

7. Wieslander G., Norbäck D., Björnsson E., Janson C., Boman G. (1997) Asthma and the indoor environment: the significance of emission of formaldehyde and volatile organic compounds (VOC) from newly painted surfaces. *International Archives of Occupational and Environmental Health,* Vol. 69, 115-24.

8. Norbäck D., Wieslander G., Björnsson E., Janson C., Boman G.(1996) Eye irritation, nasal congestion, and facial skin itching in relation to emissions from newly painted indoor surfaces, *Indoor+Built Environment,* Vol. 5, pp. 270-9.

9. Wieslander G., Norbäck D., Edling C. (1994) Occupational exposure to water based paint and symptoms from the skin and eyes, *Occup Environ Med,* Vol. 5 1: 18 l-6.

10. Norbäck D., Wieslander G., Edling C. (1995) Occupational exposure to volatile organic compounds (VOC), and other air pollutants from the indoor application of water based paints, *Ann Occup Hyg,* Vol. 39, pp. 783-94.

11. Burney P.G.J., Luczynska C.M., Chinn S., Jarvis D. (1994) The European Community Respiratory Health Survey. *Eur Respir J,* Vol. 7, pp. 954-60.

12. Ström G., Norbäck D., West J., Wessen B., Palmgren U. (1993) Microbial volatile organic compounds (MVOC): a causative agent to sick building problems. Sterling E, Bieva *C,* Collett *C* (eds) *Building Design, Technology, and Occupant Well-being in Temperate Climates ASHRAE Special Publications* 90353, Atlanta, USA, pp. 35 l-7.

SUBJECTIVE INDOOR AIR QUALITY IN GERIATRIC HOSPITALS

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Abstract
There is a need for field studies, identifying buildings with a high proportion of inhabitants satisfied with the indoor environment. Building dampness in the floor construction is known to cause chemical degradation of PVC-floor coatings, but few epidemiological studies on this topic have been pubished. Another topic of interest is indoor air quality in "ecological buildings", with unconventional building materials and architectural designs. The aim of our study was to compare subjective indoor air quality in four geriatric hospital buildings, selected to represent buildings with different age and design, irrespectively on the degree of complaints. The first building was built in 1925, and redecorated in 1955. The second building, built in 1985, had known dampness in the floor construction. The third building was built in 1993, with conventional building technique. The last building was an "ecological building" built in 1995, in accordance with anthroposophic principles. All staff (N=95) was requested to answer a questionnaire, with questions on subjective indoor air quality, 88 participated. Indoor measurements of room temperature, relative air humidity, air flow rate, illumination, VOCs, moulds, bacteria, formaldehyde, respirable dust, CO, C02, N02, and ozone were performed in all buildings. Statical analysis was performed by multiple logistic regression, adjusting for possible influence of building age, age of the subjects, gender, tobacco smoke, and atopy. Dampness in the upper concrete floor surface (75-84%), ammonia under the floor (3 ppm), and 2-etyl-1-hexanol in the air were detected in the two buildings built in 1985 and 1993. Complaints on air dryness and stuffy air were significantly more common in these damp buildings. The anthroposophic building had significantly less complaints on stuffy air, dry air and static electricity, as compared to all the other buildings. The average room temperature was 22.5-23.0 ^{0}C in the two damp buildings, 22.5 ^{0}C in the anthroposophic building, and 22.0 ^{0}C in the oldest building. All buildings had very low levels of formaldehyde, moulds, and bacteria. In conclusion, building dampness in the floor construction, may increase the sensation of air dryness and stuffy air. In contrast, architectural design and building materials used in the anthroposophic building may increase the proportion of satisfied inhabitants.
Keywords: indoor air quality, damp buildings, "ecological building", geriatric hospital, 2-etyl-1-hexanol, dry air, stuffy air.

Introduction

Complaints on poor indoor air quality may comprise a sensation of dryness, stuffy air, temperature discomfort, draught, noise, and static electricity. These complaints are common (1,2,3,4). Subjective indoor air quality has mainly been investigated among office workers or in the general population. Both the Danish Town Hall study (1) and the-Swedish Office Illness Project (3) have shown that many office workers are dissatisfied with the indoor air quality.

The perception of poor indoor environment, particularly air dryness, and stuffy air is related in the sick building syndrome, as defined by a working group of the World Health Organization (5). This syndrome comprises irritative symptoms from eyes, skin and upper airways as well as general symptoms such as headache and fatigue. Such symtoms are common in hospital workers (8). To improve the indoor air quality in hospitals, there is a need to identify factors related to the perception of good indoor air quality.

The aim of the study was to evaluate relations between perceived air quality and the physical indoor environment in hospitals.

Material and Methods

Subjects

The study was performed in the county of Ystad in southern Sweden. Four geriatric hospitals with different ages were selected with different age and design. The first building was built in 1925, and redocorated in 1955. The second building, built in 1985, had known dampness in the floor construcion. The third building was built in 1993, with conventional building technique. The last building was an “ecological building”, built in 1995, following antroposophic principles. All staff (N=95) were included in the study population. The study base was the study population observed during three months.

Assessment of subjective indoor air quality

To evaluate the perception of dry air, stuffy air, odour, annoyance from environmental tobacco smoke (ETS), temperature, draught, static electricity and noise, the personnel were asked to answer a standardized self-administered questionnaire. The questionnaire has been used in Sweden for some years and most of the qustions have been validated previously. The current version, with the designation MM040NA, was developed by the Department of Occupational Health in Örebro, Sweden (6), and has been used in the large Office Illness Study in northern Sweden (3). It contains questions on subjective indoor air quality, sick building syndrome (SBS), personal factors and the psychosocial climate of the workplace. A recall period of three months was used in the questionnaire. For each perceived climate variable, there were three alternatives to answer, “no, never”, “yes, sometimes”, and “yes, often”. Often means every week. The prevalence of weekly complaints was calculated for each subjective climate variable. The questionnaire was distributed to each hospital worker at the workplaces in January 1997, and were answered within two weeks.

Assessment ofpersonal factors and exposures in the home

Information on age, gender, smoking habits, hay fever and asthmatic symptoms was obtained from a questionnaire. The current version of the questionnaire contained four different questions covering different aspects of the psychosocial work conditions.

In a questionnaire on exposures in the home there were questions about building age, dampness, carpets, repainting and new floor last twelve months, and smoking habits and subjective indoor air quality at home.

Assessment of exposure

The technical investigation comprised a building survey and measurements of dampness in the floor, room temperature, air humidity, exhaust air flow, illumination, and the levels of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), formaldehyde, other volatile organic compounds (VOC), ozone, moulds, and bacteria. In the building survey, information was gathered on building age, types of building material, types of ventilation system, signs of building dampness and smoking restictions in the building.

The moisture content in the upper concrete floor surface was measured by a Waisala moisture instrument with probe HMP36. The instrument was calibrated with a solution of KSi04 and NaCl. Dampness in the floor was also indicated by a directreading dampnessindicator. Measurements of room temperature and relative air humidity were performed by a termohygrograf (CASELLA T 9420) during two weeks in each building. The thermohygrograf was calibrated by comparison a sling psychrometer. The exhaust air flow was measured in fifteen hospital rooms in each building by a thermoanemometer (ALNOR GGA 65 P). The thermoanemometer was calibrated by the Swedish National Institute of Building Research before the measurements. The illumination was measured in ten points in each building by Hagner’s instrument.

Nitrogen dioxide, ozone, carbon monoxide, carbon oxide and formaldehyde were sampled with passive sampling during seven days in the buildings. Four measurements in each building. Ozone was also measured in the outdoor air. Nitrogen dioxide was sampled with a passive sampling badge obtained from Toyo Roshi Kaisha, Ltd. and was analysed by liquid chromatography. Carbon monoxide was measured by a passive colorimetric detector tube (Dräger 50/a-D). Carbon dioxide was also measured by a passive colorimetric detector tube (Dräger 1 %/a-D).

Volatile organic compounds were sampled on different media (charcoal sorbent tubes Anasorb 747, and XAD-7), with four measurements in each building. The air sampling rate was 200 ml/min during six hours. The charcoal tubes were desorbed with one ml of carbon disulphide, and analysed by gas chromatography and mass spectrometry (GC-MS). Volatile organic compounds were also measured with passive sampling during seven days in each building. Airborne microorganisms were sampled on 25 mm nucleopore filter with a pore size of 0,4 mm and a sampling rate of 1,5 l/min for six hours. The total concentration of airborne microorganisms was determined by the CAMNEA method . Viable moulds and bacteria were determined by incubation on two different media. Four measurements in each building.

Temperature, air humidity, volatile organic compounds, carbon monoxide, carbon dioxide, formaldehyde, nitrogene dioxide, ozone and airborne microorganisms were measured 1.5 meter above the floor, during the study period.

Statistical Methods

Analysis of relations between subjective air quality, questionnaire data and exposures were undertaken with multivariate statistical methods. Multiple logistic regression analysis was performed in several steps using the SPIDA statistical package. Control was made for possible confounders: building age, age of the subjects, gender, smoking habits, and atopy. In all statistical analyses, two-tailed tests and a significance level of 5% were used.

Results

Personal characteristics

Totally, there were 95 personnel in the four geriatric hospitals, 88 participated (93%). The frequence of woman was 95%. The prevalence of hayfever was 16%, and 10% of the subjects reported that they ever have had asthma. The prevalence of current smokers was 3 1%. The psychosocial climate or the exposures in the home did not differ significantly between the buildings.

Buildong characteristics

The first building was built in 1925, and redocorated in 1925. The second building, built in 1985, had known dampness in the floor construction. The third building was built in 1993, with conventional building technique. The last building was an "ecological building", built in 1995, in accordance with antroposophic principles. All buildings were built of concrete or bricks, with slanting tile roofs, and all had openable windows. Building B was equipped with mechanical ventilation with both supply and exhaust air (mixed system) in the hospital rooms. The three other buildings had only mechanical ventilation in exhaust air. There were no air humidification or air cooling devices. The floor coatings consisted of poly-vinyl-cloride (PVC) material in all buildings except the antroposophic, which had linoleum and clinker.

Measured indoor climate

The average room temperature was 22,0 - 23,0 ^{0}C in the buildings. The antroposophic building had 22,0 ^{0}C. Average relative air humidity was 37% in the oldest building with the lowest air rate, and 30 – 33% in the other buildings. The exhaust air flow in the hospital rooms were between 16 and 68 m^3/h in the different buildings, where the buildings with conventional buildings technique had the highest ventilation flow. (table 1)

Exposure meausurements
Dampness in the upper concrete floor surface (75-84%), ammonia in the floor (3 ppm) and 2-etyl-1-hexanol in the air were detected in the two buildings built in 1985 and 1993 (table 1). The two other buildings had lower concentrations of these compounds. All buildings had very low levels of the other chemical and biological emissions. The average ozone concentration was 1.2 – 8.5 ppb and the average NO2-concentration was 7 – 11 ug/m^3 in the four buildings. The formaldehyde concentration was 2.0 – 7.0 ug/m, the CO-concentration was 0.16 – 0.24 ppm and CO2-concentration was 610 – 960 ppm as a average in the buildings. These concentrations were average values during 7 days.
The average concentration of viable bacteria was 50 – 80 colony forming units (cfu)/m^3 and the average concentration of viable moulds was 80 – 160 cfu/m^3 between the different buildings. The concentration of 2-etyl- 1 -hexanol was 19.8 ug/m^3 and 4.8 ug/m^3 in the two buildings with dampness. The concentration was higher in the newest building.
The average illumination was 85 – 195 lux in the different buildings.

Table 1 Measured indoor climate and exposures in the four buildings.

Type of exposure	Building A	Building B	Building C	Building D
Building age	1925	1985	1993	1995
Average room temperature	22.5 ^{0}C	23.0 ^{0}C	22.5 ^{0}C	22.0 ^{0}C
Indoor air humidity	37 %	33 %	30 %	31%
Dampness in floor surface	58 %	84 %	75 %	69 %
Ammonia in floor	0 ppm	3 ppm	3 ppm	0.5 ppm
Exhaust air flow in room	16 m^3/h	59 m^3/h	68 m^3/h	45 m^3/h
2-etyl- 1-hexanol	<1 ug/m^3	4.8 ug/m^3	19.8 ug/m^3	<1 ug/m^3
CO2 (7 days)	960 ppm	610 ppm	680 ppm	740 ppm

Perceived indoor quality
The most prevalent discomfort was a sensation of dry air. In total, 65% reported weekly complaints of dry air. Complaints on stuffy air and static electricity were also common, (Table 1).

Table 2 Three months prevalence of weekly complaints on indoor air quality in different buildings.

Variable	Prevalence (%)				
	Building A	Building B	Building C	Building D	Total
Draught	23	40	67	9	35
Dry air	62	78	94	26	65
Unpleasant odour	23	13	6	17	14
Static electricity	0	42	39	13	27
Passive smoking	0	9	11	0	6
Inadequate light	8	16	6	9	10

Building factors related to subjective indoor quality

The perception of indoor air climate was related to anthroposophical building, dampness in the concrete upper floor and emissions of ammonia in the floor and 2-etyl-1-hexanol in the air.

Complaints on air dryness and stuffy air were significantly more frequent in damp buildings and ammonia in the floor (table 3). On the other hand, there were less complaints on air dryness and stuffy air in the anthroposophic building. Complaints on unpleasant odour was not related to any factor.

Ventilation factors related to subjective indoor quality

Subjects, who worked in buildings with higher ventilaton flow, complained more often on draught. Complaints on air dryness and stuffy air were also more common in buildings with higher ventilation flow, but these buildings were damp buildings.

Perception of static electricity

Percepton of static electricity was more common in buildings with higher ventilation flow, and significantly less common in the anthroposophic building.

Table 3 Adjusted odd ratios (OR) with 95% confidence interval for relations between subjective indoor climate, and ecological building, dampness in the upper floor, ammonia in the floor and exhaust air flow.

Subjective indoor climate variable	Anthroposophic building OR (95%)	Dampness in the upper concrete floor OR (95%)	Ammonia in the floor OR (95%)	Exhaust air flow OR (95%)
Draught	ns	ns	ns	1.2 (1.0-1.4)
Stuffy air	O.l(O.Ol-0.4)	10.5(1.9-56.5)	2.5(1.3-4.7)	l.O(l.O-1.3)
Dry air	0.1(0.02-0.3)	10.2(3.0-34.9)	2.5(1.5-4.0)	1.1(1.1-1.2)
Unpleasant odour	ns	ns	ns	ns
Static electricity	0.1(0.02-0.5)	-		l.l(l.O-1.2)

Discussion

Our study show that complaints on poor indoor quality are common and was related to building dampness in the construction. Complaints were particularly common on dry air, stuffy air and static electricity. In contrast, the workers in the antroposophical building and also in the oldest building were more satisfied with the indoor air quality. This could not be explained by differences in psychosocial environment or exposures in the home.

Complaints on dry air, stuffy air and static electricity were more common in the two buildings with dampness. In an earlier study among hospital workers in southern Sweden (7), 87% of the employees complained on dry air and 44% on stuffy air. In this study (7), sensation of dry air was more common in buildings with a high ventilation flow, and also related to building dampness in the concrete slabs. Other investigators have mainly studied complaints in office workers, and there is scare information on perceived air quality in hospitals available in the literature. In comparison with the Danish Town Hall Study (1), and the Office Illness project in northern Sweden (3), complaints on dry air and stuffy air were more common in the two buildings with dampness in our study. In the Town Hall Study, 52% of the females complained on dry air and 41% complained on stuffy air. Similar figures were obtained in a study from northern Sweden (3), where 43% of the females had weekly complaints on dry air. In this study in northern Sweden there was also a relation between air dryness and building dampness. In contrast, the subjects in the anthroposophic building in our study had less complaints on stuffy air, dry air, and static electricity than in the above studies.

The levels of formaldehyde, moulds, N02, CO, C02, and bacteria were very low in our study in comparison with schools (9).

In our study we could identify certain physical factors that could be improved in order to obtain a good subjective indoor air quality in hospitals. The most important way is that dampness in the floor construction must be avoided to reduce emissions like ammonia in the floor and 2-etyl-1-hexanol in the air.
In contrast architectural design and building materials used in the anthroposophic building may increase the proportion of satisfied inhabitants.

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References

1 Skov P, Valbjörn 0, et al.: The sick building syndrome in the office environment: The Danish town hall study. Environmental International 1987;13, 339-349

2 Sundell J: On the association between building ventilation, some indoor environmental exposures, some allergic manifestations and subjective symtom reports. Indoor Air 1994; supplement 2: l-49. (Thesis)

3 Stenberg B, Hansson Mild K, Sandström M, Sundell J, Wall S: A prevalence study of the sick building syndrome (SBS) and facial skin symtoms in office workers. Indoor Air 1993;3, 71-81.

4 Norbäck D: Environmental exposures and personal factors related to sick building syndrome. University of Uppsala, Sweden , 1990 (Thesis)

5 Akimenko VV, Anderson I, Lebowitz MD, Lindvall T: The sick building syndrome. Proceedings of Indoor Air 1984, Stockholm, Swedish Council for Building Research, volume 6, 87-97.

6 Andersson K, Strid G: The use of standardized questionnaires in building-related illness (BRI) and sick building syndrome (SBS) surveys. In: Levy F. Maroni M, (eds), NATO/CCMS pilot study on indoor air quality, National Institute of Occupational Health, Oslo 1992, 47-64.

7 Nordstrom K, Norbäck D. Akselsson R: Subjective indoor air quality in hospitals – the influence of building age, ventilation flow, and personal factors. Indoor Environment 1995; 4:37-44.

8 Nordstrom K, Norbäck D. Akselsson R: Influence of indoor air quality and personal factors on the sick building syndrome (SBS) in Swedish geriatric hospitals. Occupational and Environmental Medicine 1995; 52: 170-l 76.

9 Smedje G, Norbäck D, Edling C: Subjective indoor air quality in schools in relation to exposure. Indoor Air 1997; 7: 143-150.

Is it advisable to remediate a sick building solely by a HVAC-system.

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ABSTRACT
The indoor climate of moisture damaged buildings have proved to be the cause of many building related illnesses (BRI), reported in the scientific literature. Two case studies are presented where the buildings suffered from extent mold- and bacterial growth within the building construction. This was shown through MVOC analysis of the indoor air and microbial analysis of building material. In both cases, a modern ventilation system failed to improve and prohibit "sick-building"-syndrome (SB S) symptoms of the users of the building. It was found through tracergas-technique the utmost importance of understanding the movement of odor molecules to find the emission source. Only if the emission source is found, then it is possible to mitigate a "sick building" in an efficient way.

KEYWORDS
Molds, bacteria, microorganisms, ventilation, SB S,

INTRODUCTION

The occurrence of damp buildings can be caused by water leakage, insufficient ventilation, systematic mistakes in the building construction and so on. Too much moisture in the building sooner or later leads to building damages. In Sweden these damages are seldom visible and more often they occur within the building construction or behind different surface layers as PVC-carpets, water vapor barriers etc.

Beyond rotting damages, which is the lesser part of water damages, the majority of these consists- of moldy or bacterial growth and/or increased chemical emissions. These occur as different decomposing mechanisms will initiate that, if building material is exposed to too high moisture stress in combination with other chemical factors.

Moisture related building damages usually leads to some kind of emission, such as bio-emission from microorganisms (MVOC, MPOM) or chemo-emissions from building material (VOC). These emissions can cause irritation or initiate building related illnesses of the users of the building.

A common opinion is that a well functioning HVAC-system will take care of these emissions and transport them out of reach to prohibit an impact on the users of the building. Instead of focusing on the proper function which is to supply the users of the building with air of good quality, with enough oxygen, low carbondioxide, adequate moisture and temperature. Another important aspect is to export excessive moisture (protects the building material) , carbondioxide and other by-products created by different human activities.

The HVAC system is not designed to make a “Sick building” healthy.

Common knowledge and “truth’ among field practitioners today is that moisture damaged material should be replaced, whether it is a material being damp at present or if the dampness is old and has dried out. This has also been shown as early as in 1988 (Norbäck and Widström) However, all parts of a building can not be replaced. A change of the fundamentals of e.g. concrete construction would be the same as to take down the a whole building. This action would be, if not unrealistic at least a very expensive way.

In order to reduce the emissions of “sick buildings”, the installment of a well functioning ventilation system have been a common mitigating step in communal buildings. In Sweden, a lot of schools have been remediated this way. This has however not been proved to be successful (Norbäck et al. 1998). A review article from Godish & Spengler also confirmed this in 1996.

The movement of the emissions from moisture damaged building material and microbial growth seldom follows the air movement intended in HVAC-systems. The emissions seems more to follow the laws of diffusion and chemical solubility in different surface layers, such as water vapor barriers and PVC-/linoleum carpeting.

The results of investigating some problem buildings by describing their abiotic and biotic parameters have given another perspective on the benefits of HVAC-systems.
In Scandinavia we have a quite a number of problem buildings, with odor problems and SBS of the occupants where the deposit of emission products not have been anticipated.

INVESTIGATION

CASE 1. A FAMILY HOUSE IN THE MID-EAST OF SWEDEN

The building was renovated and let out to a family of two adults and two children. Shortly after, they started to show strong SBS-symptoms, mainly extreme fatigue. Seventy-five percent of the family needed to sleep1 6 to 18 hours per day, but were still feeling drowsy. The local health care unit sampled MVOC-probes in building. The impact of microbial volatile bio-emissions was investigated by sampling the indoor air on synthetic carbon. The samples were extracted by dichloromethane. The analysis were then performed with a HP 5890 gas chromatograph equipped with a HP 5971 mass-selective detector. The analytical method were performed according to Ström et.al., 1994, except for the length of the column, which were changed to a 60 m capillary column The results are shown in table 1.

Table 1 .The concentration of volatile microbial makers of the indoor air of the building in case 1, before remediation.

Location	Mvoc 1 µg/m³ air	MVOC 2 µg/m³ air
Ref out	0,024	0,50
Basement	0,21	4,65
1st floor	0,47	5,58
1st floor	0,65	7,41
2nd floor	0,79	2,55
2nd floor	0,67	8,53
Ref.building	0.15	1.5

The concentration of volatile organic compounds representing microbial activity.
MVOC 1, the sum of the most common original "unique" microbial volatile compounds.
MVOC 2 is the MVOC 1 value, where 1-butanol and 2-methyl-1-propanol have been included.

The impact of MVOC was mainly on the 1st and 2nd floor. To establish the degree of microbial damage, the microbial biomass was investigated in representative surface areas or volumes of collected samples of building material from case 1 (Ström et al., 1994).
The results show heavily contaminated samples in the walls, while the floor construction was only slightly infected (table 2).

Table 2. Microbial biomass in the building material from case 1.

	Ref. wall area	Building wall volume	Ref insulation volume	Floor volume	Basement	
					Wall/area	Floor/area
Total fungi	$1.3*10^3$	$2.2*10^7$	$1.5*10^4$	$1.0*10^5$	$3.0*10^5$	$1.2*10^4$
Viable fungi	$1.1*10^2$	$1.6*10^2$	$1.2*10^3$	$1.3*10^3$	$9.0*10^4$	6
Total bacteria	$1.6*10^4$	$1.5*10^8$	$1.3*10^3$	$7.5*10^4$	$2.3*10^6$	$6*10^3$
Viable bact	$2.6*10^2$	$2.5*10^6$	$5.3*10^2$	$4.0*10^2$	$3.9*10^5$	6

Microbial biomass as numbers/cm' or gram.

This showed and confirmed the connection between MVOC analysis and the microbial analysis of the building material.

About ninety percent of the building above the basement was removed and a new building was erected.

In the new building, a ventilation system with heat exchange, supply- and exhaust air was installed.
In the basement there were some minor repairs based on the results of the microbial analysis.

The family moved back and soon thereafter, the SBS-symptoms returned.

Another sampling of MVOC-probes was made. The MVOC measurements after the building had been rebuilt however showed that a powerful source of bio-emissions remained (table 3.) This could be explained by that the chimney effect and the laws of gas-diffusion had not been considered properly as the highest concentration of MVOC still prevailed on the top floor.

Table 3.The concentration of volatile microbial markers of the indoor air of the building in case 1, after remediation.

Location	MVOC 1 µg/m³ air	Mvoc 2[1] µg/m³ air
Ref out	0,04	0,08
Basement	0,57	10,92
1st floor	1.32	11.83
2nd floor	1.44	13,34
Ref.building		

The concentration of volatile organic compounds representing microbial activity.
MVOC 1, the sum of the most common original "unique" microbial volatile compounds.
MVOC 2 is the MVOC 1 value, where 1-butanol and 2-methyl-1-propanol have been included.

Further investigations revealed severe microbial growth under the carpeting of the basement floor Wooden details nailed to the lower parts of the basement had similar growth on the contact surface to the wall. Emissions from PVC-carpets glued to the concrete surface in the basement were also shown.

CASE 2. A HOSTEL IN THE MID-CENTER OF SWEDEN

The personnel working in the hostel complaints over bad indoor air quality and suffer from SBS-symptoms.

The healthcare center of the Dalecarian sampled MVOC-probes in the building. The results (table 4) indicated microbial problems, and that apartment 112 had the highest MVOC-concentration of the sampled locations,

Table 4. The concentration of volatile microbial markers of the indoor air of the building in case **2**, before remediation.

Location	**MVOC** 1 µg/m³ air	**MVOC** 2 µg/m³ air	3 -**metylfuran** µg/m³ air	**2-heptanon** µg/m³ air	**2-hexanon** µg/m³ air
Ref out	0.023	0.057	. -	0.015	. -
Office	0.28	2.42	0.016	0.080	-0.035
Apartm. 112	0.50	7.42	0.050	0.28	0.10
Basement	0,075	1.58	0.012	0.044	0,020

The concentration of volatile organic compounds representing microbial activity.
MVOC 1, the sum of the most common original “unique” microbial volatile compounds. MVOC 2 is the **MVOC** 1 value, where **1-butanol** and **2-methyl-1-propanol** have been included.

The building had an old and a new built part. The old part has a basement while the new part is on a concrete slab with underlying insulation

The investigation showed a profound microbial growth in organic material placed between, the concrete slab and the floor construction of chipboard in the newly built part. At this location the peak value of **MVOC** and the microbial biomass had high correlation.

The personnel spend a small part of their working hours in the new building with the high **MVOC** and microbial biomass. Still they suffer from SBS-symptoms, even in the older part of the building.

However, no microbial growth could be detected in that part of the building.

Through the use of tracergas it was shown that there were no leakage through the ventilation aggregate, neither inner nor outer leakage.

Tracergas (Sulphurhexafluoride **SF_6**) was dosed at floor level in apartment 112 on 1st floor(fig.3).

The spreading of the tracergas was measured in three sample locations (fig. 4) .

Fig. 3. Dosing- and samplepoints in the Dalecarian hostel.

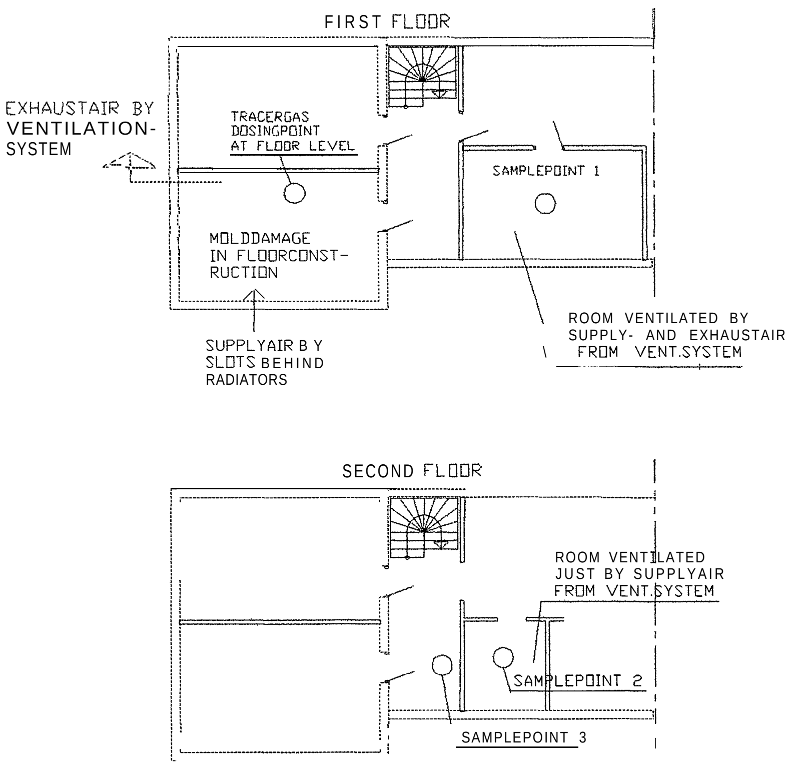
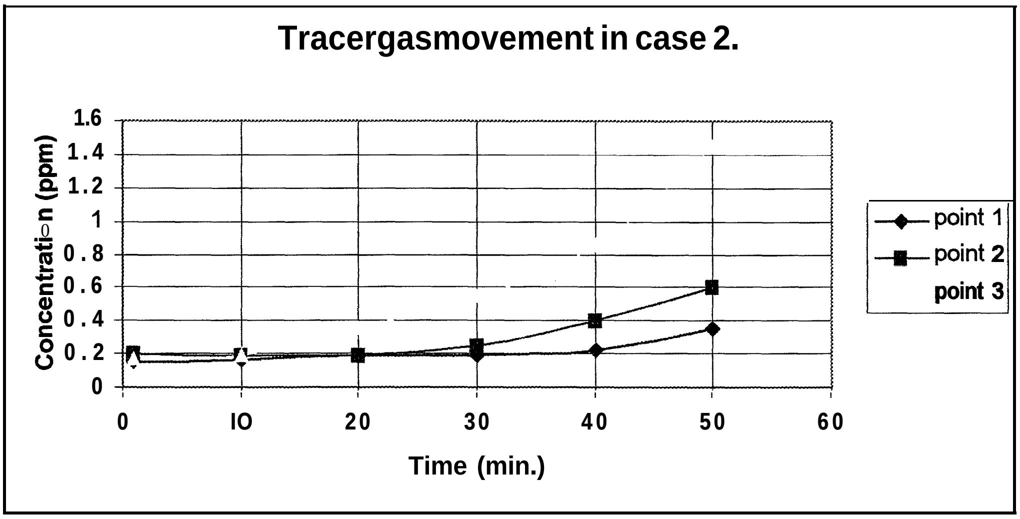


Figure 4. Tracergas movement in a hostel in Dalecarian,
point 1=Livingroom 1st floor; point 2=Office 2nd floor; point 3=Hall 2nd floor



point 1.	Ventilated supply- and exhaust air.
point 2.	Only supply air.
point 3.	Unspecific ventilation.

After 10 - 15 minutes, tracergas could be detected in all sample points. The hall on 2^{nd} floor was first to receive tracergas. The highest concentration was also found at this spot.
The office (point 2) also received a large quantity of tracergas in spite of the fact that this room only had supply air. It was anticipated that this room should not receive any tracergas. This result is remarkable due to the functioning of the ventilation system. It is also quite interesting to note that the tracergas has a high molecular weight (M_w 146). It is in the same range as many MVOC:s, e.g. mushroom smell, 1-octen-3-ol (M_w 134).

DISCUSSION

These examples show the difficulties in pointing out an emission source. There is a must to make a highly qualified follow-up of analytical data in order to avoid unnecessary costly remediating actions.

In houses on a concreteslab with heatinsulated floor construction on top, mold-/bacterial damages is not unusual in the floor construction. A common way to mitigate such houses is to remove the floor construction, place a moisture barrier of high density (HD) polyetene on concreteslab after careful cleaning and building a new floor construction on top. The HD polyetene sheet is usually folded along the outer and inner walls to allow the construction air to reach the indoor environment.

This method protects the new floor construction from dampness, but will not handle the emission source that has been created in the concrete slab. The result of this is that the odor problem will return after costly renovations. Consequently a floor construction, ventilated with supply- and exhaust air, which will take care of the emission from the concrete slab have to be installed.

It has been shown that odorous compounds from moldy building material penetrate thick HD-polyetene (Ström et al., 1994). This means that negative air pressure is not a reliable solution to inhibit odor transport. Besides the negative air pressure there is a need of an airflow, which will decrease the concentration in the ventilated floor thereby decreasing the diffusive transport through the layer of HD-polyetene. If the airflow is too low, there is a high risque that the emission of odorous substances will reach the indoor air and thereby be the cause of another outbreak of SBS-symptoms.

These examples also show that indoors environmental problems seldom are solved through ordinary ventilation systems. Even a specifically designed ventilation system will not prevent unwanted air to reach certain locations in the building.

ACKNOWLEDGEMENTS
We wish to dedicate this report to the memory of Gunnar Eckerbom a colleague and friend who tragically passed away too soon after a period of serious illness.

REFERENCES

Godish, T. & Spengler, J. 1996. Relationships between ventilation and indoor air quality: A review. Indoor Air, vol.6, pp: 135-145.

Norbäck, D. & Smedje, G. 1998. Sjuka hus symptom och astmasymptom i skolmiljön-betydelsen av inomhusluftens kvalitet och hälsoeffekter av miljöförbättrande åtgärder.

Norbäck, D. & Widström, J. 1988. "Sjuka hus"-arbetsplatser i tre län: Förekomst och karaktärisering samt effekter av miljöförbättrande åtgärder.Hygiea, vol. 97, Nr. 1.

Ström et al. 1994. Quantitative analysis of microbial volatiles in damp Swedish houses in Health implicationsof fungi in indoor environments. Ed. Samson, Flannigan, Verhoeff, Adan, Hoekstra.Elsevier Science B.V.

New function for indoor air quality evaluation

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Abstract

This paper is derived a functional expression for evaluating the indoor air quality from the generalized Weber-Fechner's law and the Fanger's "Olf method", as well as the German VDI methed. From the generalized Weber-Fechner's law we have derived the room articulation function, the visual visibility function and the thermal comfort function which are agreement with the tested results which had published by the famous researchers in the world.[1] So that it can be declared the success for finding the function for evaluating the indoor air quatity once again. And the present paper shows the generalized Weber-Fechner's law to hold, that in the generalized Weber-Fechner's law has found a differential equation as

$$dp = kf(p)dR/R^{m} \qquad (I)$$

where p = the sensible variable; f(p) = a certain arbitrary function of P to be determined by fiting the tested curve; R is the physical excited variable; k is a constant coefficient which can be balanced unit system in the equation; m is a index.

As f(P)=1, m=1, It had been called the Weber-Fechner's law. It was well known in a some text books such as [2]. For solving concrete problem, it must be determined the function f(P) and the index m, which can be found by using the data from the tested curve.

In this olfactory case we have got the function f(P) to be a function of two factors i.e. P and (a+bP). The first factor P is expressed the smell change exponentially ; the second factor (a + bP) is corrected the olfaction changed sharply at low concentration and dully at high concentration. The value m must keep minus sign which make P = 0, since it can keep at no smeller while no body complains.

The resultant form of the derived theoretical formula can express as simple as following

$$P = P_{\triangle}/(1 - \Omega P_{\triangle}) \qquad (II)$$

where an exponential function: $P_{\triangle} = 100\, e^{-4.248R^{-1}}$ and a constant $\Omega = 1.45\times10^{-3}$.

Keywords: Air Quality evaluation, Fanger's olf method, German VDI method, theoretical calaulation method, olf function.

1 Introduction

Evaluating indoor air quality is one of many difficult problem in the world. Due to human smell is decay with time; it is said, as me going to the sweet room the sweet must disappear gradually with time duration; similarly, as one going to a stinking room, the stinking can disappear gradually with the time duration. But whatever human smell is still a objective basis. So that the smell measurement must control time interval within the maximum acute sense of smell.

Under strictly controlled conditions the Fanger's "olf method" and the German VDI method were practised. These two methods give the same comparable result. This paper is derived a theoretical formula from the generalized Weber-Fechner's law which is attempted to show the theoretical proof.

2 From tests to theory

2.1 Fanger's olf function

The Fanger"olf method" is defined the pollutant to indoor air from one standard person as "1 olf", that in one room with a fresh air rate 10 l/s, it is defined as "1 decipol" polluted level.

the olf values for some pollution sources as shown in Table 2.1

Table 2.1. The olf values for some pollution sources

The pollution source	Statement	The olf values
Sedentary person	1 met	1 olf
Active person	4 met	5 olf
Active person	6 met	11 olf
moker, when smoking		25 olf
amoker, average		6 olf
materials in offices		0.05 olf/m^2 floor

The pollution level decipol is an unit pollution intensity in indoor air. Put R is a phycical excitation for smell. The PD is the subjects percentage to complain dissatisfaction. The tested curve is shown the relationship between R and PD, as shown in Figure 1.[2]

2.2 The German VDI method

This method is adopted olfactometer to measure the indoor air quality; it is taken the volatile acetone as smeller, and the value is in concentration of acetone ppm, which can be found the correspondent value in decipol, as shown in Figure 2. With acetone concentration evaluated indoor air quality had translated into the Fanger's Curve, as shown in Figure 3.

It can be seen the results from the two different methods have the same efficiency, since the smell of human being has adaptability, that make the smell to disappear with duration.

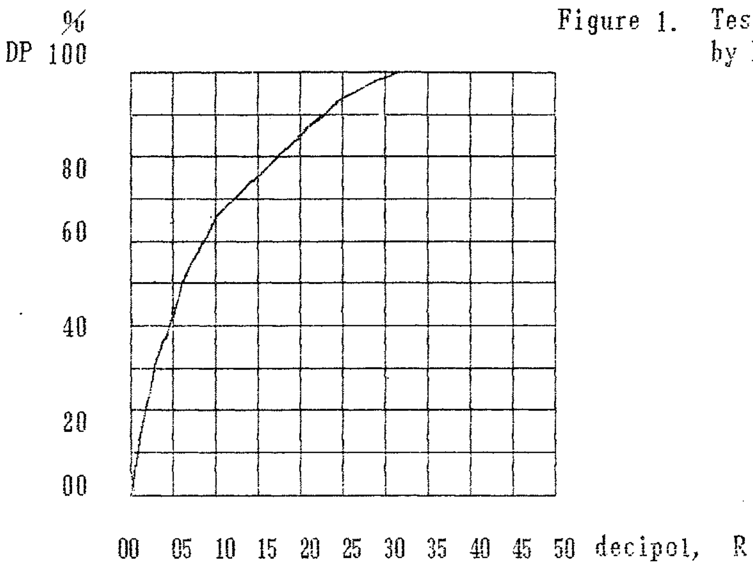

Figure 1. Test curve for olfaction by P.O.Fanger's method

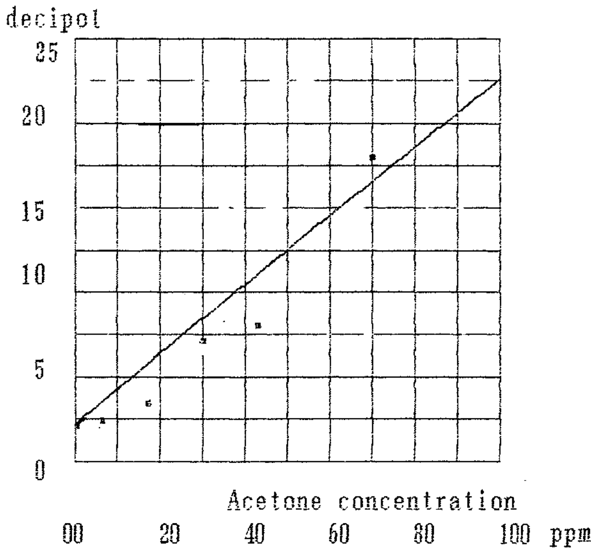

Figure 2. The equivalence of Decipol and acetone concentration ppm

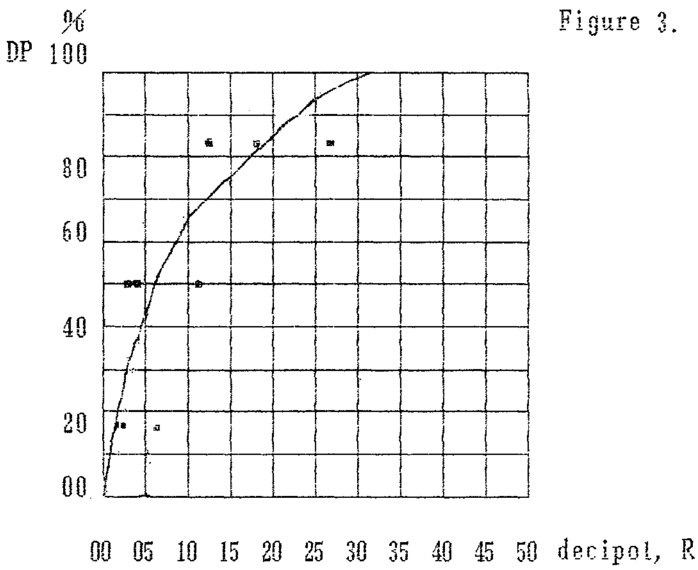

Figure 3. Test curve for olfaction by the German VDI method

2.3 Theoretical method

This is the key part. in this paper, so that. in this part the process of performing mathmatical calculation need in detail

3 Developing the olfactory formula

3.1 At first cut and try

let us put $f(p)=p$, then the expression (I) can be written as separated variables expression as

$$dp/p = kdR/R^{m} \qquad (1)$$

which has The integration as follows

$$\ln p = -k/(m-1)R^{m-1}+C \qquad (2)$$

where C is a integral arbitrary constant. To solve for p we have

$$p = e^{-k/(m-1)R^{m-1}+C} \qquad (3)$$

where k, m. and C to be determined by three points on the tested curve.

Let us put $m-1>0$, then $R\to 0$, $P\to 0$ [this point is on the Fanger tested curve]; as $R\to\infty$, the $P=100\%$. Under these conditions, the expression (2) can change as follows

$$p = 100\, e^{-k/(m-1)R^{m-1}} \qquad (4)$$

where $C=\ln 100=4.60517$. As take other two points on the Fanger curve as $R=20$, $P=84.61$; $R=15$, $P=75.38$. Substituting these values into equation (4) respectively, we get two simultaneous equations for k and m as follows,

$$\ln 84.61 = \ln 100 - k/(m-1)20^{m-1}$$

and $$\ln 75.38 = \ln 100 - k/(m-1)15^{m-1}$$

which can be simplifying as

$$k/(m-1)20^{m-1} = 0.167117723 \qquad (5.1)$$

and $$k/(m-1)15^{m-1} = 0.282628198 \qquad (5.2)$$

In the last two equations as the second one is divided by the first one, we have in which can be solved by m as

$$m=1+\ln(1.6911925)/\ln(20/15)=2.826439503 \qquad (6)$$

To substitute m in expression (6) into expression (5.1) we get

$$k=0.167117723\,(m-1)20^{m-1}=72.591 \qquad (7)$$

The solution is

$$P=100\, e^{-39.745\, R^{-1.82649503}} \qquad (8)$$

where $C=\ln 100=4.60517$.

The calculated results list in 4-th column in Table 1, which though differs from Fanger's curve; but it nears the state of three right tested points by VDI method, as shown in Figure 4. This curve and Fanger's curve have two common points. But on all other points the calculated points are smaller than tested values. So, we will be cut and try to take reference points at the section with greater slope.

3.2 Cut and try again

As take other two points on the Fanger curve to try. such as $R=10$, $P=65.39$; $R=15$,

Table 1. Data comparison of Fanger PD to calculated PD

no	decipol values R	PD from Fanger's curve	PD by formula (8)	PD by formula (9)	PD by (16)	PD by formula (17)	PD by (16)
1	0	00.00	00.00	00.00	00.00	00.00	00.00
2	1	13	0.00	1.4	1.403	13	13.5
3	2	22	0.00	12.0	12.21	26.0	28.16
4	3	31	0.48	24.27	25,16	34.81	38,79
5	4	37	4.25	34.58	36,41	41.16	46.84
6	5	46.15	12.22	42.76	45.59	46.15	53.21
7	10	65.39	55.28	65.39	72.26	59,9	72.74
8	15	75.38	75.38	75.34	84.60	66.9	83.33
9	20	84.61	84.61	80.86	91.63	71.33	90.31
10	25	93.08	89.48	84.37	96.16	74.41	95.31
11	31.3	100	92.89	87.31	100.00	77.24	100
12	∞	100.00	100.00	100.00	100.00	100.00	100.00

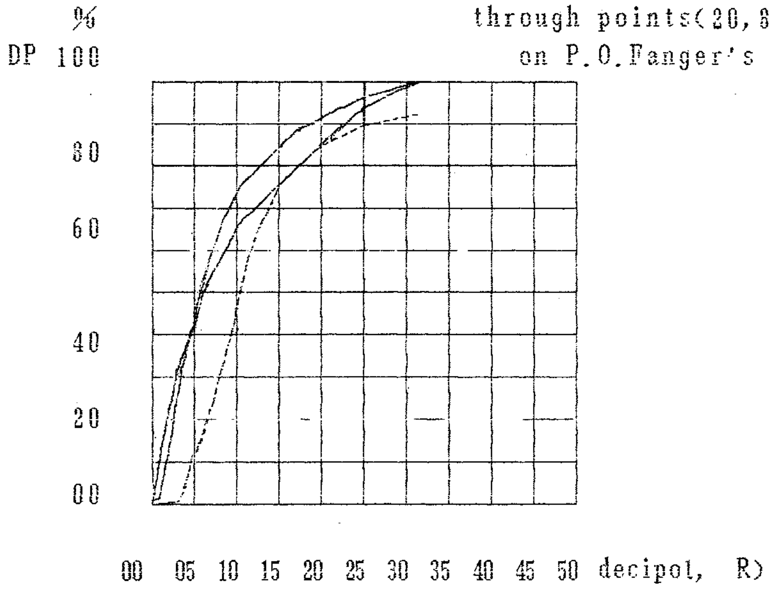

Figure 4. The broken curve is calulated, pass through points(20, 84.61);(15, 75.38) on P.O.Fanger's curve

P=75.38. Substituting these values into equation (4) respectively. we get two simultaneous equations for k and m as follows:

$$\ln 65.39 = \ln 100 - k/(m-1)10^{m-1}$$

and

$$\ln 75.38 = \ln 100 - k/(m-1)15^{m-1}$$

which can be simplifying as

$$k/(m-1)10^{m-1} = 0.424800844 \qquad (5.1')$$

and

$$k/(m-1)15^{m-1} = 0.282628198 \qquad (5.2')$$

As the second one is divided by the first one in the last two equations, we have

$$(15/10)^{m-1} = 1.503037728$$

hich can be solved by m as

$$m = 1 + \ln(1.503037728)/\ln(15/10) = 2.00499 \approx 2 \qquad (6')$$

To substitute m in expression (6') into expression (5.1') we get

$$k = 0.424800844(m-1)10^{m-1} \approx 4.248 \qquad (7')$$

The solution is

$$P = 100\, e^{-4.248 R^{-1}} \qquad (9)$$

From calculated results, it can be sees,, as the reference points influence the curve inclination as shown in Figure 4 and Table 1. The data at 4-th column are two co-points with Fanger's curve which are point (15, 75.38) and point (20, 84.61) where is located at the section of smaller slope of Fanger's curve ; similarly, the data are calculated by formula (9) at 5-th column are two co-points with Fanger's curve which are point (15, 75.38) and point (10, 65.93), where is located at the section of middle slope; again the data at 7-th column are two co-points with Fanger's curve which are point (5, 46.15) and point (1, 13). But the rate of selected function is changing still slowly. whichever that Pd value can not reaches 100% in finite value of R decipol. Unless R=∞. It is said, the function f(P)=P can not unsuitable, It requires further improving.

3.3 New function selection

let us take a fit function as f(P)=P(a+bP), which has partial fractions as

$$\frac{1}{P(a+bP)} = \frac{1}{aP} - \frac{b}{a(a+bP)} \qquad (10)$$

where a,b are constants to be determined to fit the tested curve.

Substitute the partial fractional function(10) into the differential equation (1), we have

$$dP/aP - b\,dP/a(a+bP) = k\,dR/R^m \qquad (11)$$

The integration is

$$\ln P - \ln[1+(b/a)P] = -ak/(m-1)R^{m-1} + aC \qquad (12)$$

or writting as

$$P/[1+(b/a)P] = [100\, e^{-k/(m-1)R^{m-1}}]^a \qquad (13)$$

Put factor in right square brackets be the symbol □ present 8 solution of formula (8) or (9), then we get

$$P/[1+(b/a)P] = \square^a \qquad (14)$$

from the last equation to solve for P as

$$P = \frac{\square^a}{1-(b/a)\square^a} \qquad (15)$$

where as put a=1, b/a=Ω. then

$$P = \frac{\square}{1-\Omega\square} \qquad (16)$$

According to Fanger's condition, 31.3 decipol, PD=100(%); to calculate □ by formula (9), on this case PD=87.32(%). Fro3 formula (16) we can determine number $\Omega = 1.453441759 \times 10^{-3}$. Calculated results by formula (16) list in last column of Table 1.

From the data in the Table 1, we can he seen that as the reference points in the middle of the curve, the difference is larger nearing two ends. So that we must take the reference points at the end near zero, due to it is very sensitive, and the influence is very small due to the correct at another end. Let us take points ii, 13) and (5, 46), then at first point we have $0.13 = e^{-k}$, $k = -2.04022082$; at second we have $0.46 = e^{-k5^n}$, $n = 0.600196876$. PD function is

$$P = 100\ e^{-2.04022082/R^{0.600196876}} \qquad (17)$$

A series data of □ are calculated by the formula (17) list in Table 1 also. On this case DP value merely 77.24 corresponds to 31.3 decipol which corresponds DP=100 on Fanger's curve. So the Ω in expression (16) has determined as

$$\Omega = (100 - 77.24)/100/77.24$$
$$= 2.946659762 \times 10^{-3}$$

According to expression (16) we can calculate the DP data list in the last column in Table 1. The corresponding curve as shown in Figure 5. It can be seen, this curve can be epitomized the regularity in Fanger's olf method and German VDI method.

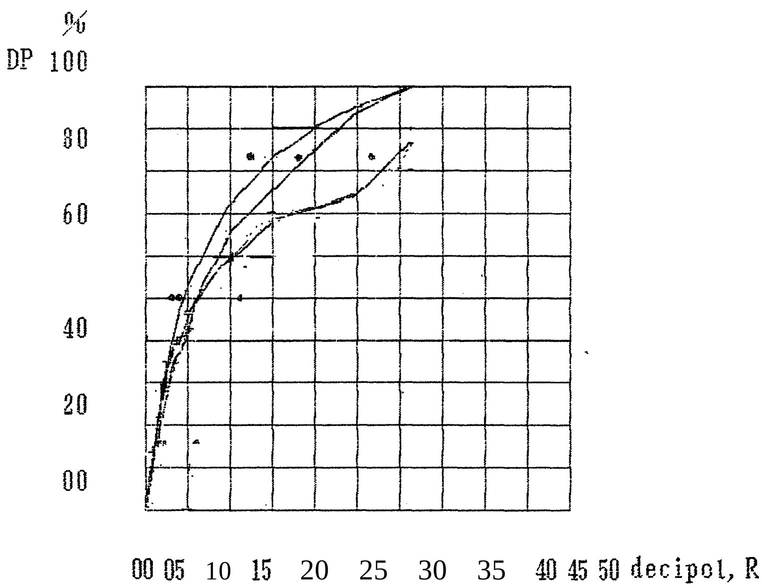

Figure 5. the theoretical curve drawn by formula derived

4 Conclusions

The coefficient function f(P) in the generalized Weber-Fechner law had been found, This function is a product of two factors. the inverse of which has two partial fractional functions. one factor make an usual exponential change and another factor modifying the exponential change with the human smell. It is shown. the theoretical formula is real reflection human that is sharp for low concentration of smeller and it is dull for high concentration. the theoretical curve is almost forming an outer envelope for all test data, which shows the human olfactory character to be sharp in low concentration smeller and dull under high concentration smeller. It can seen, This law is summarized from practice but it is higher than that practice.

The generalized Weber-Fechner law have been successfully found some function between the physical excitation and physiological sensation, such as, the room articulation function, the visual visibility function, the thermal comfort function and now the olfactory function. from one by one successful experiences the prediction can be redeclared, that the generalized Weber-Fechner law is a half universal formula from which can be found a sensational function to describe the relationship of a corresponding physical excitation, provided the tested curve has been work up.

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THe author thanks the German Professor Karl A.J.Gertis very much for kind send to me the new information for German new achievement[4]. which recalls my original interest to apply the generalized Weber-Fechner law to olfactory problem.

6 REFERENCES

1, Q.G.Chen, G.Z.Ma, X.Z.Ding, Y.C.Chen & Y.N.Wei(1990); A Generalized Weber-Fechner Law. INDOOR AIR'90 Vol.i, pp769-774.

2. Ken-ichi Kimura(1975); Fundamental Theories of Building service. Tokyo. Chapter 6, pp72-76.

3. P.O.Fanger(1988); The olf and decipol. Indoor Air Quality. ASHRAE JOURNA October 1988

4. Rudolf Schwab and Dr.Erhard Mayer(1996) Unterschiedliche Verfahren zur Geruchsbewertung; "FANGER CONTRA VDI". CCI 30(1996) H.10.S.18-23

Selection of a Contractor - Evaluation of Bids

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Abstract
Factors other than price are being considered increasingly often during the procurement process. These other factors can include quality, competence, resources, recycling, longevity of materials and constructions, or the impact on the environment of the implementation. The tendering procedures of a great number of public works projects carried out in Sweden during the last few years have been studied. Special attention has been devoted to the evaluation of factors other than the price in relation to the choice of contractors. This project also aims to show how bids are evaluated in practice and, on the basis of this, suggest a bid evaluation model better suited to the requirements of the client. The aim of this paper is to describe some models that are commonly used to evaluate bids concerning tendering of public works.
Keywords: tender evaluation, evaluation models, contractor selection

The need for development in the construction sector

In order to create and maintain a construction sector that can meet the requirements for increased effectiveness, the construction sector and the client in particular must devote more resources to research and development. The construction sector in Sweden and the rest of Europe are marked by a slow rate of development, especially in comparison to the fixed industries. Many of those involved in the branch hold the view that the reason for the present slow rate of development is that the forms of procurement that are usually used discourage innovation. [1] In order to create larger dealing freedom, new forms of procurement must be developed.

Construction work clients are striving for forms of procurement that provide a secure process, as well as a long-term innovative process. The choice of form of procurement and the choice of method for evaluating the bids affect the pre-requisites for reaching this goal (see *Fig. 1).*

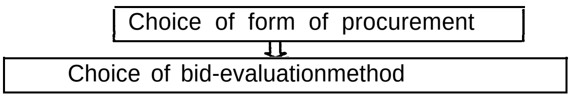

Figure 1 *The choice of form of procurement affects the choice of bid-evaluation method.*

One effect of the increased desire of contractors to develop new, more effective solutions will probably be bids with larger variations in price and size than is usual today. All bids must, however, be able to be compared and evaluated in a similar way. At the same time, the evaluation methods ought to reward good suggestions with innovative content.

The more freedom a contractor is given, the more possibilities there is of finding solutions that fulfil the client's requirement of limited use of resources. However, the more freedom they are given, the more factors must be taken into account when evaluating the bids (see *Figure 2).*

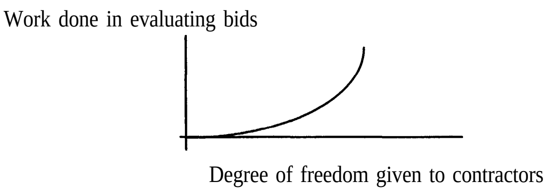

Figure *2 Relationship between the extent of evaluation work and the degree of freedom given to contractors*

The factors may have to do with the environment, quality, safety, etc. Evaluation of these factors is accomplished with the help of evaluation models that include price factors.

In addition to being a tool for selection, the evaluation models serve to direct contractors' bid presentations toward the project goals. Another reason for using evaluation models is that the client, in creating a model, gains a better knowledge of what is important in construction.[2,3,4]

Objective and Limitations

The main objective of the research project is to contribute to the development of a construction sector that is more inclined toward innovation. The aim of this paper is to

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[1] **Atkins, 1994**
[2] Janson Patric, **1970**
[3] Ericson Gösta, **1971**
[4] **Totalentreprenad, 1981**

review models for evaluating bids and describe currently occurring bid evaluation methods for road-building procurement in Sweden.

The research project is selective to include procurement of road projects outside of the cities.

Scientific Method

An evaluation model must help ensure that the client's wishes are fulfilled. Figure 3 shows the various factors that contribute to an evaluation model.

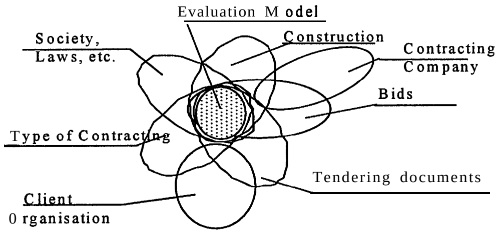

***Figure** 3 Evaluation model for bids, seen as a system composed of several sub-systems.*

Based on this reasoning, it is appropriate to choose the way of viewing the system as the starting point for the research project.

Research work can be regarded as a process of finding things out. The knowledge that is generated forms the basis for the next phase. The method in the first phase has involved studying the literature and empirical research of various models used in the reference project.

A great many theories exist about how to achieve the best results in evaluation of bids. This paper deals with the structure and description of some general theoretical principles, including various evaluation methods and how evaluation models are constructed, as well as the most common evaluation models used by the Swedish National Road Administration.

After going through the literature, it can be stated that there are shortcomings in the theories regarding the effect of the evaluation method on the end result for different forms of procurement and types of project. Moreover, there is no analysis of how the methods and models that are used affect the propensity for innovation.

Various Selection Principles for Choosing a Bid

The following is the principal system for choosing a bid in procurement situations:

Pre-qualification		
lowest price	Price evaluated	Price set by the Client
Verification of minimum requirements	Verification of minimum requirements	Verification of minimum requirements
	Evaluation of soft parameters	Evaluation of soft parameters

***Figure** 4 Principal alternatives for choosing a bid.*

As shown by the diagram, several of the principles can occur together. Above all, there are almost always some sort of minimum requirements. Then there are methods that are more or less mixtures of these. For example, after pre-qualification, the point system can be used for soft parameters and pricing.

Pre-qualification involves evaluating various aspects of the bidding company's performance. A pre-qualified contractor must be capable of carrying out the planned project as the client wishes. The aim of pre-qualification is mainly to make it possible to select the contractors who will be asked to take part in a procurement process.

Choice of contractor based on lowest price: First it is verified that the bids contain everything that is asked for in the invitation to tender. The bids often contain conscious deviations (reservations) from the invitation to tender. For the sake of price comparison, the evaluators must know what it would cost to remove these reservations. The evaluators can either request this information from the contractor or make an estimate themselves.

Verification of minimum requirements: When using this method, it must be verified that the so-called soft parameters fulfil certain minimum standards; they are then given a mark of 'pass' or 'does not pass.'

Choice of contractor based on evaluation of soft parameters*: The parameters are given different values, depending on how well they fulfil the client's requirements. They can be assigned different importance or weight in relation to each other, based on what type of project it is. The parameters are added up, yielding a total sum that indicates to the client which bid to choose.

Choice of contractor based on quality with set price: When a procurement is for a job in which the construction company has the main responsibility for the project, it is possible to set a maximum price for the building and then evaluate only the qualitative parameters of the bid.[5] [6]

Establishing an Evaluation Model

When it has been decided that the bids will be evaluated according to different parameters, an evaluation model is then established. The client begins by deciding which parameters will be included in the model. After this is established, how the parameters are to be evaluated must be defined. Usually this involves giving each parameter points on a scale from 1 to 5 or 1 to 10. The easier it is to evaluate a parameter, the greater the scale that may be assigned to that parameter. A scale of 1 to 10 may sometimes be seen as too large a spectrum for obtaining a correct evaluation every time. However, a more limited scale may cause information to be lost unnecessarily. It must also be observed that the distinctness of the rankings decreases with a more limited scale.

Difficulties may arise when the criteria must be evaluated, since some factors are not directly measurable. Hard parameters such as price pose no problem in this respect, as variations in price can be directly correlated with a point system. The value of a soft parameter, however, is often impossible to measure directly, and it is therefore significantly more difficult to assign it points. Methods must be found of relating the qualities of the parameter to some sort of point scale. Price parameters must be assigned points within the same system as the soft parameters in order to allow comparative weighting.

After the point scale is established, the relative importance of the different factors is defined. Weights are numbers that represent the absolute or relative importance in the total evaluation. Weighting must form the basis for a comparison of the different factors so that total values can be found for the various bids. Weighting can be assigned to parameters chosen for the evaluation model in several different ways. One method is to give each factor a monetary value. These values are totalled and the weight of the factors is proportional to their monetary value.

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* **Soft parameters are all evaluated aspects that are separate from price/expenses.**

[5] **Byggindustrin, 1968**

[6] **Pernu Pirjo, 1997**

Another alternative is to weight the parameters by comparing them all with each other and deciding for each comparison which parameter is most important.[7] [8]

Yet another weighting system involves comparing each soft parameter to the cost parameter. The increase in cost that keeps the total value of the bid the same when a certain soft parameter is raised from the least possible to the highest possible level indicates the weight for that parameter.[9]

Comparative weighting of factors can be accomplished by different methods that do not necessarily all yield the same results. The easiest way is, of course, to assign the same weight to all the parameters. Then they can be totalled as is *(straight comparison)*, and the contractor with the highest total should be chosen.

The most common way of comparing parameters with different weights is to add up the products of each parameter's value and weight *(weighted comparison).*

Dividing each product by the maximum points possible for the parameter removes the significance of the differences in value scales between parameters *(corrected weighted comparison).* Then the focus is on how large a portion of the total value the parameter occupies in the given bid.

This reasoning requires that all parameters are independent of each other. In reality, it is highly unlikely that the parameters would not relate to each other in various formations. The theoretical way of solving this problem is to form a new parameter from the overlap between two parameters. It can, however, be a question of a large number of factors and the ones that are important to the project must be isolated.

Sensitivity Analysis

Before beginning to use the evaluation model, a sensitivity test must be performed, including a critical examination of the reliability of different types of evaluation. The analysis should answer the following":

- Which uncertainties and variations must be taken into account when assigning weight and points?
- How do such uncertainties affect the result of the evaluation, i.e. the rankings?
- How large a change can one make in the given weighting system before it affects the results, i.e. the bid rankings?

The client must be especially conscious of the fact that assigning points to soft parameters is in many cases rife with risk of subjectivity, randomness and mistakes in measurement.

The evaluation models of the Swedish National Road Administration

Representative evaluation models used by the Swedish National Road Administration between January 1994 and June 1996 have been studied. The models are continuously under development, but several basic principles can be discerned.

Just half of the Road Administration's regions make use of evaluation models for new procurement investments. Procurement of up-keep and maintenance projects in all regions is carried out using evaluation models produced centrally at the Road Administration. The Swedish National Road Administration uses three different criteria for selecting bids:

- Evaluation of soft parameters and price according to an evaluation model,
- Verification and evaluation of established minimum requirements,
- Lowest price.

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[7] Janson Patric, 1970
[8] Andresen Inger, 1997
[9] Ericson Gösta, 1971
[10] Ericson Gösta, 1971

The evaluation models that exist all arrive at their evaluation based on both soft parameters and price. Evaluation models contain criteria for both the contractor and aspects of the project itself. The most common parameters are:

- **The contractor's quality-control system.**
- **The bidder's ability to complete the task.** (The client considers the size of the bidding company, physically and economically)
- **Previous projects.** (For example: what was the quality level, how was the traffic situation taken care of, did the contractor present unmotivated demands or have a tendency to make things difficult? In certain cases it is worth points if the client has previous experience working with the contractor.)
- **Partners offered** (experience, qualifications, number of years in the business, etc.)
- **Contractor's models, methods for procurement of sub-contractors**
- **Production time** (time when the project will be opened to traffic, identification and minimisation of traffic disruptions)
- **Production methods,** as well as alternative course of action in case of any extreme circumstances. (Points can also be awarded to contractors that demonstrate that they have paid the most possible attention to the environment through environmentally-friendly methods and equipment and environmentally-safe storage and material handling.)
- **Aesthetics** (For projects that include bridge-building, aesthetics will be judged based on the opinion of a special committee.)
- **Secondary offers** (In some few cases points will be awarded if the bid is accompanied by secondary offers that make it possible for the client to reduce costs).

The Road Administration's evaluation models take into account 5-6 soft parameters with 3-4 sub-parameters each. The weight of the main parameters varies between 5% and 20%. The bid total is heavily weighted (40–60%) in all the models.

Points are usually awarded with the help of guides that specify which information the bid must include in order to receive certain points. In most cases, a scale of 0 to 4 or 5 is used for every sub-parameter.

The amount of points in the bid total (if it is given points) is decided based on how much the bid total deviates from the lowest bid. The remaining bids receive points depending on how many percent higher they are than the lowest bid, on a linear scale (see Figure 5). If the contractor requires an advance on the payment, the bid total is usually increased according to a nationally established interest rate. For larger contracts a longevity factor is often also evaluated and assigned points.

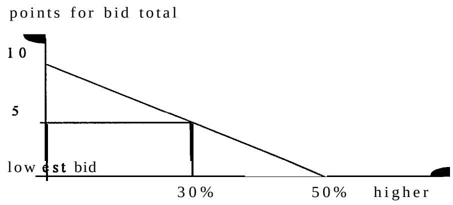

Figure 5. Example of how the bid total can be assignedpoints.

The points are worked into a total sum by dividing the total points of each parameter by the maximum points for the main parameter and multiplying by the weight. Lastly, these points are added to figure out the *(corrected weighted comparison).*

New Investment

The most common type of evaluation model in use in procurement of new investments is a function of several different parameters, P:

$$\text{Model} = F(P1, P2, \ldots Pn)$$

The model shows how the values work out to a points total, T_p, for each bid; this forms a basis for decision-making when a bid must be chosen. The bid that has the highest T_p will be accepted.*

$$T_p = \Sigma_{j=1}^{j=n} P_j \ , \text{ where } P_j = (\Sigma_{j=1}^{j=n} a_{ij} \ * \ w_j)/ \Sigma_{j=1}^{j=n} a_{ijmax}$$

w_j is the weight for parameter j and $\Sigma_{j=1}^{j=n} w_j = 1$.

a_{ij} represents for certain P several sub-parameters (the target for the contractors to aim at). a_{ij}/a_{ijmax} is then a value of how well the target for parameter *ij* is fulfilled. For some values of P (the parameter for evaluating aesthetics, environmental consequences, etc.) a is a mark given by a special evaluation group, such as an aesthetics committee, for example.

For so-called hard parameters (for example investment expenses, longevity expenses or interest expenses for advance payments) a is a point that has a direct relationship to the monetary value.

As shown in the formula above, every P is divided by the maximum point total that the parameters can reach, a_{ijmax}. This provides a degree of goal achievement and means, practically speaking, that the effect on the total sum that would have originated in the parameter's point range is eliminated.

This model allows the parameters, P, that the client regards as most important to have a stronger effect on the ranking than other, less important parameters (see *Example 5).*

Example 5 Assuming that there are two bids, A and B, the evaluation model appears as follows:

The bid was awarded the following points:

			A	B
1.	Quality	O-5 pts weight: 35%	3	1
2.	Time	O-5 pts weight: 10%	1	3
3.	Price	O-8 pts weight: 55%	4	4

Both bids have received 8 points in all but A has the highest total points: A: 3*0.35+1*0.10+4*0.55=3.3
B 1*0.35+3*0.10+4*0.55=2.85

There are other types of models used less often. In one region a model has been developed for procurement of new investment objects from general contractors in which the wishes of the customer are taken into account in a more pronounced way. In this model points are also given if the bids include secondary offers that are better than the client's wishes. This model does not include weighting the parameters; instead, the bids are ranked according to their point totals.

Another type of model multiplies the points for respective parameters by their weights, and these products are added up to calculate the total value of the bid. The total value is then divided by the bid total, expressed in thousands of Swedish crowns. The quotients are then finally multiplied by 1000 *(see Example 6).*

Example 6.

Assuming that there are two bids, A and B, which received points as shown in the table below.

	Total pts. Bid A	Total pts. Bid B
Competence	5	4
Quality	6	8
Organisation	3	2
Traffic	8	6
Bid	500 000	450 000

The total points for both bids are calculated:
A: ((5*0.35+6*0.35+3*0.15+8*0.15) / 500)*1000= 9.9
B: ((4*0.35+8*0.35+2*0.15+6*0.15) / 450)*1000 =ll.l

* Under the condition that the 'most economical& advantageous bid' must be chosen.

An attempt to provide the contractors with a little more space was made in the evaluation model and calculation methods for the points of the bid total. Normally the lowest bid alone gets to receive maximum points for this parameter. Instead, the lowest bid, along with all other bids up to 5% higher, received the maximum points, raising the significance of the soft parameters.

The Up-Keep and Maintenance Model

Since 1996, up-keep and maintenance procurements have been made with the help of an evaluation model that verifies how well certain requirements are met. All requirements had to be fulfilled to a certain degree and the bids could receive extra points for parameters that were especially well fulfilled.

If the company fulfils some of the different parameters' surplus requirements, a percentile deduction is made from the bid at the bid-total level. In this way, meeting the requirements especially well can have an effect on the ranking of the bid totals.

The invitations to tender ask for bids in two parts: one with the bid total and the other including additional offers and suggestions. The parts containing the additional offers and suggestions are opened first. The reason for opening the bid totals afterwards is to avoid the risk of subjective evaluations affected by the prices.

Invitations to Tender

In all the cases studied, it was specified that the bids be evaluated in a professional way, and that the most economically advantageous bid should be selected, which means that more than just the price of the bid must play a significant role in the process.

In general, it can be said of the descriptions in the invitation to tender about how the bid evaluations will be carried out that they are insufficient. When an evaluation model is used, it is not always provided with the invitation to tender.

In the administrative introduction to the invitation to tender, under the heading 'Form and Content of the Bid,' it is specified which information and documents must be enclosed with the bid. The parameters listed under the heading 'Basis of Evaluation' can not always be taken solely on the basis of the 'Form and Content' section. It is left up to the contractors themselves to decide which documents ought to be enclosed with the bid

An empirical study of how the evaluation models are utilised in practice has been made. Some of the conclusions that can be drawn from it are that the total value of a bid can vary based solely upon which documentation has been enclosed with the bid, and that the better the client knows the contractor, the less the significance of the documentation.

Conclusion/Continuing Research

Alternative methods for evaluating bids have been reviewed in brief. To reach the overall goal of a more innovative construction sector, the conditions of procurement must be altered. The invitation to tender must be designed to show contractors clearly that innovative input is expected and will be rewarded. Evaluation models must be created that allow this rewarding to occur.

The evaluation system should also function in such a way that there is documented follow-up of the project results, which can then be compared with evaluation models and procurement data (see Figure 6).

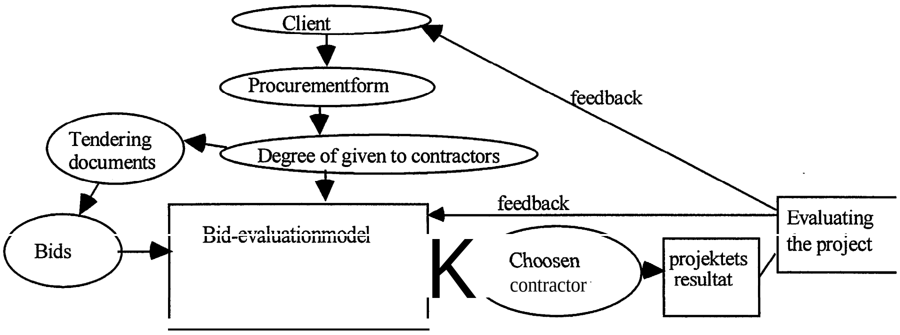

Figure 6. System for follow-up and experience-based feedback on project results.

Experience-based feedback will help in part when the client must choose principles for evaluation. It will also act as the basis for the creation of a new evaluation model or the improvement of an existing one.

In the next stage of the research project, selected methods for bid evaluation will be analysed and one or several model methods will be developed that are suitable for bid evaluation in contracting that encourages innovation on the part of those involved in the construction process. During the analysis, special attention will be paid to the effect of evaluation methods on innovative contributions. More concretely, one of the questions will be how much the evaluation method can encourage innovation from those involved.

As a basis for development of evaluation models, an empirical (quantitative) study will be undertaken and several interviews (qualitative) will be conducted. The analysis of current evaluation methods will also form the basis for suggestions for evaluation models that will work for the procurement of innovative projects. The suggested models for bid evaluation in innovation-oriented procurement will be duly tested in some actual construction projects, thereby testing the hypotheses

Literature and References

Atkins WS Internationa Ltd, Strategies for the European Construction sector. A program for change, Europakommissionen, 1994

Russell Jeffrey S, Hancher Donn E and Skibniewski Miroslaw J *"Contractor prequalification data fir construction owners"* Construction Management and Economics 1992 vol. 10 pp. 117- 13 5.

Janson Patric, *Totalentreprenad,* Byggforskningsradet Rapport 47: 1970

Totalentreprenad, 2.Värderingsmodeller, KBS rapport 8 1

Ericson Gösta, *Anbudsvärdering vid totalentreprenad,* Byggforskningsradet Rapport 24: 197 1

KBS-rapport 81, Stockholm 1971)

Janson Patric, *Anbudsvärdering av totalentreprenader*, Byggforskningsradet, Rapport R47: 1970

Olsson Erik, Peming Ulf, *Värdeanalys*, Falköping 1970

Ullstad Erland, *Bedömningsmetoder vid upphandling av bostadsomrhden på totalentreprenad,* Inst. for byggnadsfunktionslära, LTH, 1970

Att jämföra anbud vid totalentreprenad - en ny fransk metod, Byggforskningen informerar 1/68

Sundin Erik, *Modell för anbudstävlan*, Byggnadsindustrin 8.69

Sundin Erik, *Totalvärdering avpris och miljö*, Byggnadsindustrin 14.69

Programutformning och bedömningsmetoder vid upphandling av bostadsområden, del 1 Anbudsbedömning, Statens institut for byggnadsforskning, Stockholm Nov. 1970

Fallon Carlos, *V&de och beslut*, 1970

Andresen Inger, Decision methodology for design of environmentally friendly buildings, Department of Building Technology, Norwegian University 1997

Health effects of installing a new ventilation system in school buildings

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Abstract

Apart from the home, school is the most important indoor environment for children aged 6-16 and there is a growing concern about the impact on health of the school environment. It has been shown that the air exchange rate often is low, but there are few studies on the relation between health symptoms and school ventilation. We have studied changes in the prevalence of symptoms compatible with the "Sick building syndrome" among school pupils, and related this to the installantion of a new ventilation system in school.

Pupils in 39 randomly selected schools participated in the study. Recording of symptoms was made by means of a self-administered questionnaire that was answered twice by 1476 pupils aged 7- 16; in 1993 and again in 1995. Information on the installation of a new ventilation system in school between 1993 and 1995 was obtained by inspections by the researchers and information from the caretakers of the buildings. Both years exposure measurements were also performed in the schools. The changes between 1993 and 1995 in the prevalence of symptoms in pupils attending schools that got, respectively did not get, a new ventilation system, was analysed.

The classrooms that had got a new ventilation system had in 1995 a higher air exchange rate and the relative humidity, concentration of carbon dioxide and formaldehyde was lower, compared to the other classrooms. Symptoms compatible with the Sick building syndrome in the pupils had increased after the two years, but pupils attending schools with a new ventilation system reported less nasal and general symptoms, and more skin symptoms compared to the other pupils.

Thus, installing a new ventilation system in school could reduce both exposure and SBS symptoms in the pupils, but the effect may vary for the different groups of symptoms.

Keywords: schools, pupils, Sick building syndrome, ventilation system, exposures

1 Introduction

Poor indoor air quality in non-industrial buildings has been supposed to cause different health problems, among them the Sick building syndrome (SBS) which involves various non-specific symptoms such as eye, skin and upper airway irritation, headache and fatigue [1]. The role of building ventilation for SBS has been investigated in several studies, mainly among office workers. Godish has recently reviewed this literature and concludes that the studies have reported mixed results, but that there is limited evidence to suggest that an outdoor air flow up to 10 l/s per person may be effective in reducing the prevalence of sick building symptoms and occupant dissatisfaction with air quality [2]. Children are likely to be affected at a lower concentration of various pollutants, thus studies on SBS among children should be helpful in understanding the phenomenom, but there are few such investigations.

Apart from the home, school is the most important indoor environment for children aged 6-16 and there is a growing concern about the impact on health of the school environment. Several studies have been published showing deficiencies in the indoor air quality in schools. The concentrations of dust and airborne and dustbound microorganisms and pet dander are relatively high [3-5]. The air exchange rate is low, the concentration of carbon dioxide (CO_2) is high and the ventilation standards are often not fulfilled [6-8]. The possible impact on the health of the pupils of improving the school ventilation should be an important aspect, but there are, to our knowledge, few studies on this subject. However, studies on SBS among school employees have not found any relation to a low air exchange rate as expressed by a high concentration of CO2 [8, 9]. These studies are typically cross-sectional and there are few longitudinal studies relating SBS to changes in the ventilation parameters.

In the Swedish School Environment Project we have undertaken a number of studies on asthmatic symptoms and SBS among school personnel and pupils and have related these to the school environment. In this paper we present results concerning the effect of a new ventilation system in the school building on exposure factors and symptoms compatible with the Sick building syndrome among school pupils.

2 Material and methods

2.1 The study population

In 1992, we randomly selected 39 primary and secondary schools in the county of Uppsala in mid Sweden. The schools varied in respect to factors such as age, construction and size. For each primary school, 1 class in the 1st and 4th form, respectively, were randomly chosen. Since the number of secondary schools was lower, 3 classes in the 7th form were randomly chosen, except for 1 school where there were only 2 classes in this form. In total, 615 pupils in the 1 st form (being approximately 7 years old), 657 pupils in the 4th form (being approximately 10 years old) and 762 pupils in the 7 th form (being approximately 13 years old) were invited to participate in the study.

2.2 Information from the pupils

Recording of symptoms was made by means of a standardized self-administered questionnaire that was mailed to the home adress of the puils in January-February 1993. To those who answered 1993 and who were still attending the same school, the questionnaire was sent again two years later, in december 1994-january 1995.

The questionnaire requested information on diseases and present symptoms and on domestic exposure. There were 16 questions on symptoms compatible with the Sick building syndrome. These symptoms were grouped into symptoms from the skin (facial itching, facial rash, itching on the hands, rashes on the hands, and eczema), nasal (nasal catarrah, and blocked up nose), throat (dryness in the throat, sore throat, and irritative cough), and eyes (eye irritation and swollen eylids), as well as some general symptoms (headache, abnormal tiredness, sensation of getting a cold, and nausea). These questions asked if the pupil had experienced the symptom during the past 3 months "no, never", "yes, sometimes (I -3 times/month)", "yes, often (1-4 times/month) or "yes, daily". For each symptom group the prevalence of at least weekly symptoms was calculated for both years, as well as the number of symtomatic days/month and the number of pupils reporting more, respectively fewer, symptomatic days 1995 compared to 1993.

The questionnaire also contained some questions on other symptoms like asthma and allergies, the composition of the family, smoking habits and domestic exposures such as environmental tobacco smoke and signs of dampness in the home. There were also some questions about the psychosocial environment at school.

2.3 Assessment of exposure

Exposure measurements were performed in the schools during spring 1993 and again in the winter of 1995. In each school we chose 2-5 classrooms. In primary schools each class usually had its own classroom, and we thus chose the classroom of the classes that had got the questionnaire. In secondary schools, the pupils attended different classrooms depending on the subject, and we chose classrooms so that the diffrent school buildings were represented. Some of the classes changed classrooms between the two years, thus it was not always the same rooms that were investigated both years. In 1993 a total of 98 classrooms was investigated, and in 1995 10 1. Of these, 5 1 were investigated both years.

We inspected the buildings and noted details of their construction including type of ventilation system. We measured the air exchange rate with a tracer gas decay method. Based on the air exchange rate and the room volume, the outdoor air flow was calculated. Information on the installation of a new ventilation system between 1993 and 1995 was obtained from the caretakers of the buildings, as well as on other building measures undertaken in the school, like repainting or new floor covering. In each classroom we measured the temperature, relative humidity, and the levels of C02, respirable dust, formaldehyde, other volatile organic compounds (VOC), VOC produced by microorganisms (MVOC), moulds and bacteria. The methods have been described elsewhere [7].

2.4 Statistical methods

MC Nemar's test was used to analyse possible differences in the prevalence of the symptoms between the two years. Differences between measured exposure in the classrooms that got, respectively did not get, a new ventilation system were analysed using the Mann-Whitney U test.

Analysis of the relationships between the symptom variables, other questionnaire data and the occurrence of a new ventilation system were undertaken with multivariate methods. Multiple logistic regression analysis was performed in several steps using the SPIDA statistical package [10]. Each outcome variable was analysed separately. A crude analysis was made including only the outcome variable and the occurrence of a new ventilation system. The different outcome variables were then tested against other questionnaire data one at a time and some personal factors were found to be important confounders. Separate analyses were undertaken controlling for these confounders, and for other building measures that had been undertaken at the same time as the installation of the new ventilation system.

In all the statistical analyses, two tailed tests and a significance level of 5 % were used.

3 Results

3.1 Information from the pupils

Out of the 1879 selected pupils that were attending the same school during the whole period, 1476 (79 %) answered the questionnaire both years. The non-responders were more freauent among the secondary school pupils compared to the primary school pupils (response rate 76 % and 8 1 %, respectively).

The answers to the different questions on SBS symptoms are given in table 1, presenting the prevalence 1993 and 1995 of at least one weekly symptom. For nasal and general symptoms the increase of symptoms between the two years was statistically significant.

	1993	1995	p-value*
Eye symptoms	1.2%	2.0 %	**n s**†
Nasal symptoms	7.1 %	8.7 %	co.05
Throat symptoms	5.6 %	6.9 %	n s
Skin symptoms	**10.1 %**	**9.7 %**	n s
General symptoms	15.9 %	24.8 %	<0.001

* Differences in symptom prevalence between the years analysed by McNemar´s test.

† Not significant.

‡ At least one weekly symptom during the past 3 months.

Table 1 Prevalence of SBS symptoms‡ in 1476 school pupils 1993 and 1995

Calculating the monthly number of symptomatic days showed that there was a significant increase of symptoms between the two years for all symptom groups. The percentage of pupils reporting more symptoms 1995 than 1993 was for symptoms from the eyes 7 %, nose 30 %, throat 27 %, and skin 12 %, while more general symptoms was reported by 41 %. Most of these differencies concerned a change of the rating from "no, never" to "yes, sometimes". For general and nasal symptoms, however, there was also changes toward experiencing these symptoms "yes, every week". There was also a considerable recovery from symptoms between the two years.

3.2 Exposures in the school buildings

The mean year of construction of the school buildings was 1960, with the oldest being built around the year 1900 and the newest in 1992. The majority (82 %) of the buildings had 1-2 storeys and 38 % had a basement. Most (63 %) were mainly built of stone.

In 1993, 77 % of the investigated classrooms did not fulfil the Swedish ventilation standard demanding a supply air flow of approximately 8 l/s per person and a concentration of CO_2 below 1 000 ppm [11]. The corresponding result for 1995 was 63 %. Out of the 98 classrooms that were investigated 1993, 11 were situated in buildings that later got a new ventilation system. Of these, 3 schools had natural ventilation only, 1 school had a mechanical exhaust air system, and 3 schools had mechanical supply and exhaust air system, with the air supplied according to the traditional dilution principle. In 1995, 101 classrooms were investigated, of which 12 had a new ventilation system. In all cases, the new system consisted of displacement ventilation with mechanical supply and exhaust air. Cooling or humidifying of the air was not applied.

Data on exposures 1993 and 1995 in classrooms with, respectively without, a new ventilation system are given in table 2

	1993			1995		
	later got new ventilation			new ventilation after -93		
	yes	no	p-value*	yes	no	p-value*
Air exchange rate (ach)	0.8	2.6	<0.01	5.0	2.8	<0.01
Outdoor air flow (L/s p)	1.9	5.8	<0.01	13.9	7.3	<0.001
Carbon dioxide (ppm)	1120	975	n s†	825	1050	<0.05
Room temperature (°C)	24.5	23.5	n s	21.5	22.0	n s
Relative humidity (%)	42	38	n s	31	35	<0.05
Formaldehyde ($\mu g/m^3$)	8	6	n s	4	10	<0.01
VOC ($\mu g/m^3$)‡	128	90	n s	54	85	n s
Respirable dust ($\mu g/m^3$)	26	18	<0.01	12	14	n s
Viable bacteria (10^3 cfu/m^3)	0.57	0.96	n s	0.53	0.54	n s
Total bacteria ($10^3/m^3$)	79.7	48.7	n s	41.2	32.3	n s
Viable moulds (10^3cfu/m^3)	0.73	0.43	n s	0.14	0.16	n s
Total moulds ($10^3/m^3$)	44.7	39.1	n s	10.6	12.4	n s
Microbial VOC($\mu g/m^3$)§	0.13	0.40	n s	0.13	0.22	n s

* Differences in measured exposure between each ventilation group analysed by Mann-Whitney U test.

† n s=not significant

‡ Sum of volatile organic compounds < C_{13}.

§ Sum of 8 identified compounds.

Table 2 Exposures 1993 and 1995 in classrooms with, respectively without, a new ventilation system

In 1993, the air exchange rate was lower in the classrooms that later got a new ventilation system, and the concentration of most of the measured exposures was higher, although only for respirable dust the difference reached statistical significance. In 1995, after the installation of the new ventilation system, these buildings had a higher air exchange rate, and the relative humidity, and the concentration of CO_2 and formaldehyde were significantly lower than in the other buildings. However, there were no significant differences in the concentration of respirable dust, or airborne total or viable moulds and bacteria.

3.3 Relations between symptoms and the occurrence of a new ventilation system

In 1995, 143 of the pupils attended schools where a new ventilation system had been installed in the major part of the school since the investigation 1993, and 1 333 of the respondents did not attend such a school. There were no differences in 1993 between these two groups concerning the important personal factors related to SBS (age, gender, allergic diseases or the ratings of the psychosocial school environment).

Data on the relation between symptoms and the occurrence of a new ventilation system are given in table 3. Pupils attending schools with a new ventilation system reported more seldom an increase of nasal symptoms, and this relationship was significant both in the crude analysis and after controlling for personal factors (data not shown), and other building measures, respectively. After controlling for other building measures, pupils in the new ventilation schools less often reported an increase of general symptoms and less often a decrease of symptoms from the skin. In the crude analysis there was also a significant relation between attending a school with a new ventilation system and reporting less eye symptoms 1995 than 1993, but this relation was not found in the corrected analyses. Controlling for the personal factors did not cause any significant changes in the results (data not shown).

		Odds Ratio	(Confidence Interval)*	p-value
Eye symptoms,	increased	1.1	(0.5-2.1)	n s
	decreased	1.4	(0.6-3.4)	n s
Skin symptoms,	increased	1.2	(0.6-2.5)	n s
	decreased	0.3	(0.1-0.8)	<0.05
Nasal symptoms,	increased	0.3	(0.2-0.7)	<0.001
	decreased	0.9	(0.5-1.6)	n s
Throat symptoms,	increased	0.7	(0.4-1.2)	n s
	decreased	0.7	(0.4-1.3)	n s
General symptoms,	increased	0.5	(0.3-0.8)	<0.01
	decreased	1.5	(0.9-2.4)	n s

* Controlling for repainting, and new floor covering in the school.

† Analysed by logistic multiple regression.

Table 3 Significant relations between changes in symptoms between 1993 and 1995 and the occurence of a new ventilation system†

4 Discussion

4.1 Methodological aspects

There was a higher response rate among primary school children, compared to those in secondary school. Also, questionnaires on SBS have not not been used to this age group before, and there is a lack of "objective" clinical methods for these kind of symptoms to validate questionnaire data against. Hallén & Juto have, in adults, compared subjective ratings of nasal congestion with rhinostereometry and found a good agreement [12]. However, the possible bias between age groups or due to the method of collecting the symptom data, should not be systematicly different between those who attended the schools that got a new ventilation system and those in the other schools.

The tendency of reporting symptoms could be influenced by awareness of the school having, or not having, got a new ventilation system and expectations regarding its health effects. One could speculate that attending a school where remodelling is undertaken could affect the perception of the school environment, and the reporting of symptoms. If this was the case, such effects should be caused by different kinds of remodelling measures. But in this study we found that the other remedial activities that took place, in some schools, together with the installation of the new ventilation system, mainly repainting and new floor covering, were related to an increase of symptoms, and when controlling for these measures, the effects of the ventilation installation was strenghten.

4.2 Effects of a new ventilation system on measured exposure

In all the classrooms, the new ventilation system resulted in an increase of the air exchange rate, but the effects on airborne pollutants was not equally consistent. Gaseous pollutants, but not particles, tended to be lower in the classrooms with a new ventilation system. This is in accordance with studies from other indoor environments. Increasing the outdoor air flow in an office building reduced the concentration of formaldehyde, other VOC and CO_2 [13]. In three otherwise identical domestic houses, but with different ventilation systems, it was found that the concentration of particles and bacteria did not differ [14]. In a trial with different outdoor air flows in an operation theatre it was found that the number of persons present was the most important factor determining the particle concentration [15].

4.3 Relations between symptoms and the occurrence of a new ventilation system

Pupils attending schools with a new ventilation system reported less nasal and general symptoms, and more skin symptoms. Walinder et al [16] investigated personnel working in 12 of these schools with "objective" clinical methods and found that nasal congestion and higher levels of inflammatory cells in the airways, were more common among those working in schools with a poor air exchange rate, and less common among those working in schools with a displacement ventilation system. When it comes to the finding that skin symptoms seemed to be more impared among pupils attending the new ventilation schools, one could speculate that this could be due to the lower relative air humidity in these classrooms.

We do not know which were the qualities of the new ventilation system that were responsible for the results: the displacement principle, the increased flow, or the fact that the ducts, filters and diffusers (at least in some of the schools) were new and, hopingly, clean.

5 Conclusion

Installation of a new ventilation system in schools could reduce symptoms compatible with the Sick building syndrome in the pupils.

6 Acknowledgements

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7 References

1. Akimenko W, Andersen I, Lebowitz MD, Lindvall T. The “sick” building syndrome. In: Berglund B, Berglund U, Lindvall T, Sundell J, eds. Indoor Air volume 6 (Evaluation and conclusions for health sciences and technology). Stockholm: Swedish Council for Building Research, 1986:87-97. (D 13 : 1986)
2. Godish T, Spengler JD. Relationships between ventilation and indoor air quality: A review. Indoor Air 1996;6: 135-45.
3. Dybendal T, Elsayed S. Dust from carpeted and smooth floors VI. Allergens in homes compared with those in schools in Norway. Allergy;49:210-16.
4. Munir AKM, Einarsson R, Shou C, Dreborg SKG. Allergens in school dust. J Allergy Clin Immunol 1993;91(5):1067-74.
5. Mouilleseaux A, Squinazi F. Airborne fungi in several indoor environments. In: Samson RA, et al, editors. Health implications of fungi in indoor environment. Amsterdam: Elsevier, 1994: 15 5-62.
6. Routsalainen R, Teijonsalo J, Seppanen 0. Ventilation and indoor air quality in Finnish schools. In: Flatheim G, Berg KR, Edvardsen KI, editors. Indoor air quality in practice - moisture and cold climate solutions. Proceedings of a symposium 1995 June 18-21; Oslo, Norway. Norwegian Society of Chartered Engineers and International Society of Indoor Air Quality and Climate, 1995:489-93.
7. Smedje G, Norbäck D, Edling C. Subjective indoor air quality in schools in relation to exposure. Indoor Air 1997;7: 143-50.
8. Willers S, Andersson S, Andersson R, Grantén J, Sverdrup C, Rosell L. Sick building syndrome symptoms among the staff in schools and kindergartens: Are the levels of volatile organic compounds and carbon dioxide responsible? Indoor Built Environ 1996;5:232-5.
9. Norbäck D, Torgen M, Edling C. Volatile organic compounds, respirable dust, and personal factors related to prevalence and incidens of sick building syndrome in primary schools. Br J Ind Med 1990;47:733-41.
10. Gebski V, Leung 0, McNeil D, Lunn D. SPIDA users manual. Version 6. Eastwood Australia: Statistical Computing Laboratory, 1992.
11. AFS 1993 : 5 Ventilation och luftkvalitet, Arbetarskyddsstyrelsen, 1993.
12. Hallén H, Juto J-E. Correlation between subjective and objective assessment of nasal hyperreactivity. Otorhinolaryngol Rel Spec 1994;56: 5 l-4.
13. Menzies R, Tamblyn R, Farant J-P, Hanley J, Nunes F, Tamblyn R. The effect of varying levels of outdoor-air supply on the symptoms of sick building syndrome. N Eng J Med 1993;328(12):821-7.
14. Reponen T, Nevalainen A, Raunemaa T. Bioaerosol and particle mass levels and ventilation in Finnish homes. Environment International 1989; 15 :203-8.
15. Kruppa b, Rüden H. The influence of various air exchange rates on airborne particles and microorganisms in conventionally ventilated operating rooms. Indoor Air 1996;6:93-100.
16. Wålinder R, Norbäck D, Wieslander G, Smedje G, Erwall C. Nasal swelling, lavage, and the indoor environment in schools. In: Frang T, ed. Proceedings of "Allergistämma ′96", 1996 Nov 7-8, Stockholm. National Institute of Public Health 1996:112:131.

ISIAQ Guideline Moisture Control in Cold Climates

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Abstract

ISIAQ (International Society of Indoor Air Quality and Climate) is producing Guidelines dealing with different aspects on Indoor Air Quality. The first one is a result from ISIAQ Task Force I called "Control of moisture problems affecting biological indoor air quality" (1) and was published at the conference Indoor Air '96 in Nagoya. The second one, on principles for investigation of IAQ complaints, not yet published, is a result of work done in ISIAQ Task Force II. At present'there are nine Task Forces working.

One of the Task Forces, "Moisture Control in Cold Climates", is just starting up. There was a Workshop, ISIAQ task group for microbial contaminant control, at the conference Healthy Buildings '97 in Washington in September -97. The workshop was chaired by Aino Nevalainen from the National Public Health Institute in Finland and Tom Follin from the consulting company BARAB in Sweden. The workshop was the real starting point for the work. At the same time another Task Force is working with the same kind of problems in Hot and Humid Climates.

The guidelines are meant to be practical handbooks to be used when solving existing IAQ problems and to avoid that kind of problems.
Key words: contamination, damages, guideline, moisture, SBS.

1. Introduction

Moisture is, at least in the Nordic countries, the main reason to bad indoor air quality. Moisture in the indoor air causes problems due to very low RH during winter time. The problem is to little moisture, -not to much! Lack of moisture in the air doesn't contaminate the air, it make it dry. Contamination of the air is mostly caused by degradation in/on building materials due to to much moisture. Not even among the scientists are those facts always quite clear.

ISIAQ (International Society of Indoor Air Quality and Climate) has organised two task groups in order to produce international guidelines dealing with the moisture related IAQ problems in cold climates and in hot and humid climates.

The guidelines are meant to be practical handbooks to be used when solving existing IAQ problems and to avoid that kind of problems.

2. The work

The Task Force, "Moisture Control in Cold Climates", is just starting up. There was a Workshop, ISIAQ task group for microbial contaminant control, at the conference Healthy Buildings '97 in Washington in September -97. The workshop was chaired by Aino Nevalainen from the National Public Health Institute in Finland and Tom Follin from the consulting company BARAB in Sweden. The workshop was the real starting point for the work. During the conference 15 persons, in different ways active in the IAQ field, have offered their assistance with writing contributions to the planned Guideline.

At present (Januari -98) 4 (!) have delivered some kind of material or promised to write parts of the guideline. A first draft structure of the guideline is sent to the contributors during Christmas -97.

Problems in houses due to moisture not always causes IAQ problems. As some kind of limitation is needed the guideline will concentrate on moisture problems affecting the indoor air.

3. The draft contents in ISIAQ Guideline: Moisture Control in Cold Climates.

INTRODUCTION

Introduction
Word list
Critical RH-levels

PHYSICS

Air movements, different pressures, depending on time of the year (due to different temperatures) or on ventilation system.
Moisture, water vapour (indoors-outdoors, in materials- equilibrium), liquid water (in materials, in the ground, sources), ice/snow.

MEDICAL ASPECTS

Contaminants (caused by moisture) possibly causing health effects.
Symptoms-reasons.

SAMPLING, WHY and HOW

- Mould, Rot, Bacteria
- Moisture
- v o c
- Odours

MEASURING, WHY and HOW

- Moisture (Scanning, MC, RH)
- Air Leakage
- Temperature

TYPICAL SIGNS ON MOISTURE DAMAGES

- Photos on Moulds, Rot, Salt, degradation of Plaster, Bricks, Wood, Floorings, Roofings, Bathrooms etc.
- Odours.

EXAMPLES ON DIFFERENT KIND OF DAMAGES

- Foundations
  - Problem
  - Investigation
  - Retrofits
  - Results
- Walls
  - Problem
  - Investigation
  - Retrofits
  - Results
- Floors
  - Problem
  - Investigation
  - Retrofits
  - Results
- Roofs
  - Problem
  - Investigation
  - Retrofits
  - Results
- Bathrooms
  - Problem
  - Investigation
  - Retrofits
  - Results
- HVAC/Ventilation
  - Problem
  - Investigation
  - Retrofits
  - Results

DESIGN

Moisture secure
Reparable
Easy to maintain

CONSTRUCTION

Keep dry
Keep klean

USE

Maintenance
- floors
- bathrooms
- roofs
- walls
- HVAC/Ventilation

REFERENCES

Different litterature from different countries. Even in other languages then English.

4. The result

The resulting Guideline is going to be practical. It will contain the reasons to different kind of moisture related damages causing contaminations of the indoor air. Advices on measurings and possible cures or treatments will be given. Advices on how to avoid moisture problems will be given. Environmental issues are going to be observed. A booklet of about 80 pages is planned and will, if everything workes out, be published in 1,5 year.

Acknowledgements

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References

1. Flannigan B., Morey Ph. (1996) *ISIAQ-guideline* ***Control of moisture problems affecting biological indoor air quality.*** ISIAQ Inc, Ottawa Canada.

Three green buildings from Venezuela: proposals for climate sensitive design

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Abstract

Three green buildings designed to provide psychological, physical and social well being through improved comfort combined with lower energy consumption and less generation of wastes are explained.

The first case is the project "Habitar el Dispositivo" "T*o inhabit the device"* which was awarded a prize in an international competition in Tenerife in 1995 and in which the integration of bioclimatical and architectural concepts in a livable device is proposed; the second case is a bioclimatical house for Tamare, Venezuela, which incorporates design principles from traditional indigenous, colonial and oil company houses in the Maracaibo lake basin to generate a prototype adapted to contemporary urban Venezuelan problems; and the third case is a low cost variation of the second building.

Digital and analogical models of the first two prototypes have been built to analyze sunlight and shadow behavior and computer simulations permitted to predict thermal performance. Thermal satisfaction was 89.5% during typical summer and winter 24 hour periods for the Tenerife building; and in the Tamare house, assuming a higher comfort temperature, acceptable for summers in developing countries, we achieved 95% of satisfaction when the building is ventilated at night and closed during daytime. The third proposal has not been thermally evaluated yet.-

Some bioclimatic principles which are proposed for the summer of the Tenerife house and during the whole year of the Tamare house are: 1) minimization of radiation gains through windows and facades by solar protection, 2) minimization of conduction heat flow and thermal oscillations by-adequate positioning of insulation and mass and use of external light colors 3) control of air changes; and 4) bioclimatic landscaping. Some passive cooling techniques are: 1) comfort ventilation; 2) nocturnal convective cooling; and 3) direct evaporative cooling. During the winter of the Tenerife house, the summer principles will also perform adequately (insulation, mass, etc.) while protection from the cool winds and the passive heating technique, direct solar gain, is proposed.

Construction of the Tenerife and Tamare houses will begin in mid 1998 with financing from the Canarian and the European Economic Community for the Tenerife house, and PDV, the Venezuelan Oil Company, for the Tamare house. Financial assistance for the construction of the third prototype has not been secured yet. In all three cases thermal parameters and some indoor air quality parameters will be monitored after construction, to evaluate performance of these prototypes.

Keywords: Sustainable design, bioclimatical design, passive cooling and heating, housing

1 Introduction

Many bioclimatical buildings have been designed which seek to perform more efficiently. However, the performance of these is generally achieved by the addition of technological devices to a project, producing a work that is many times rejected by its dwellers, due to its high cost, complex appearance and even more complex utilization. In contrast to these proposals, we propose an integral relation between architecture and bioclimatism making these devices form part of man's space.

2 To inhabit the device: a bioclimatical house for Tenerife, Spain.

2.1 Architectural principles

As a base principle for the reencounter between architecture and bioclimatism, we proposed "to inhabit the bioclimatical devices", this is, to make them form part of man's space. Thus emerges, the inhabited triangular chimney, that directed towards the northeast, collects the wind and circulates it through indoor spaces.

As a second base principle, we proposed "to integrate the technological devices in an architecturized device". Thus appears the "Fortran" wall, called so because of its simple but operational technological devices which someway resemble old computer Fortran cards.

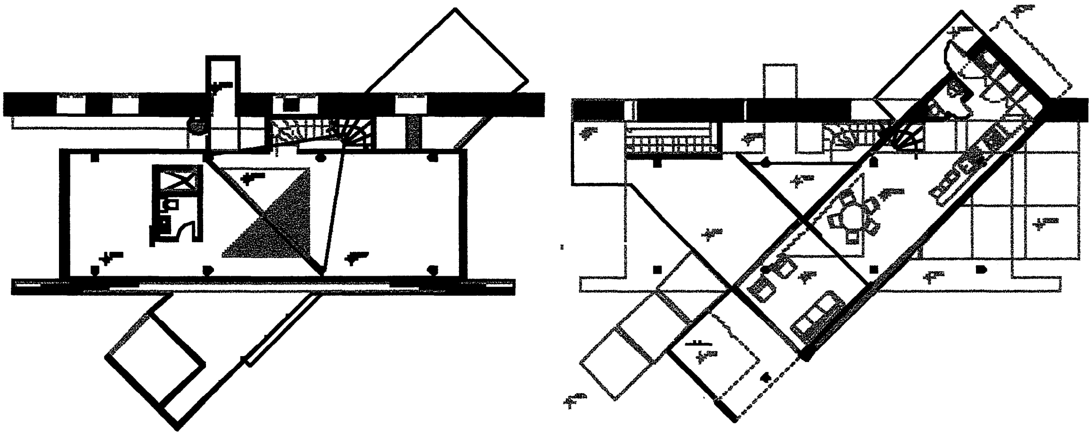

Fig 1 Plans of the Tenerife House

2.2 Bioclimatical techniques and passive systems

According to Givoni [1] bioclimatical techniques permit to reduce heat gains by conduction, radiation and convection through walls and windows in summer, and to reduce heat losses in winter. Passive cooling systems transfer incident energy to natural energetic deposits, or heat sinks, such as the air, the upper atmosphere, water and earth. Passive heating systems store and distribute solar energy without the need of complex controllers for its distribution.

Climate variables of southern Tenerife (Reina Sofia Airport) were analyzed using Fanger's and Givoni's method, in relation to the thermal comfort zone. Two situations were typified: winter, from November to May and summer, from June to September. In winter, night values are located in the passive warming zone, and towards noon, in the comfort zone. In summer, the values are located in the comfort zone during the night and in the comfort ventilation zone during most of the afternoon. Therefore, warming is required during the winter nights and cooling during the summer days; control of heat losses is also necessary in winter nights and control of heat gains in summer days. The building protects from the sun and opens to the fresh winds in summer, while in winter it opens to the sun and is closed to the cool winds.

2.2.1 Bioclimatical techniques

1. **Solar and eolic orientkion.** The direction of the building answers to the sun and to the wind. The top floor is oriented with its main shaft east-west, with openings to the south and protected in the other faces, answering to the solar direction. The ground floor is oriented 45 degrees in relation to the first floor answering to the dominant trade winds from the northeast. In the intersection of the two volumes and guided towards the northeast is located the triangular eolic chimney.
2. **Protection of openings** in **summer.** All the openings are adequately protected in summer. The transparent facade of the second floor has a rollable louvered mechanism permeable to the wind and impermeable to the light, that permits to regulate radiation to the dormitories, avoiding overheating.
3. **Mass and insulation as thermal regulators.** Indoor thermal mass and external insulation are used to store heat from the winter days and "cold" from the summer nights and to avoid heat gains in summer and losses in winter.
4. **Light external colors.** The external color of the facades is white, which reduces heat gain by conduction through walls and roofs, necessary in summer.
5. **Solar protection.** The overlapping of crossed volumes and the Fortran wall generate shaded areas, non-existent due to the lack of trees.
6. **Protection from cold winds.** The "Fortran" wall serves as thermal regulator of external conditions, protecting from the cold winds in winter but also has small windows that permit cross ventilation through spaces to generate comfort in the summer. The louvered windows can be also closed in the winter nights to protect the transparent facade and to reduce the coefficient of superficial conductance.

2.2.2 Passive cooling and heating systems

1. **Direct solar gain.** Energy gains in winter are by radiation through windows and then stored for night use.
2. **Convective night cooling.** Nocturnal ventilation cools internal mass of floors and walls during the night, reducing its surface temperature, helping to keep the building cool during daytime hours.
3. **Direct evaporative cooling.** The openings of the "Fortran" wall and of the eolic chimney have containers with water, to add moisture to incoming air and decrease air temperature.
4. **Comfort Ventilation.** High air speeds in the zone make it easy to introduce air into the house and extend the thermal comfort zone to the upper comfort values.

2.2.3 Renewable energy sources

Solar energy is proposed for water heating and photovoltaic cells to complement grid electricity and both located on the Fortran wall.

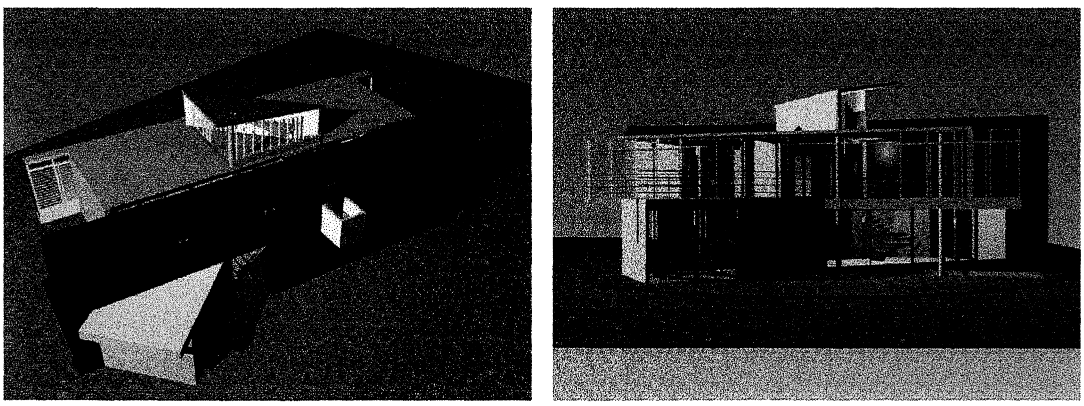

Fig 2 North and south views of the Tenerife House

2.3 Thermal evaluation of the proposal.

To determine the effectiveness of our proposal, the computer program for simulation of thermal behavior in dynamical regime CODYBA [2], was used. Data from the meteorological station was used to determine a typical summer day, July 15, and for a typical winter day, January 15. The percentage of satisfied with internal conditions was calculated with Fanger's Predicted Mean Vote method. A 75 kg male, with a height of 1,70 mts., and a moderate activity of 81 w/m^2 was used as reference. In winter, clothing was 1.2 CLO and air velocity 0.1 m/s. In summer clothing was 0.8 CLO and air velocity 1.5 m/s. ASICLIMA [3] was used to determine solar position during different days of the year, thermal transmitance values of envelopes and heat flows through the different plans of the facades.

During winter days the daytime average temperatures are 21.2 °C in the first floor and 21.6 °C in the ground floor, while the daytime external average is 19.6 °C. The average percentage of satisfied during the winter day are 87% and 86% respectively.

During the winter nights the average temperatures are 21.1 °C in the first floor and 20.7 °C in the ground floor, while the external average is 17.5 °C. The average percentage of satisfied during winter nights is 90% and 87% respectively.

During the summer days, daytime average temperatures are 24.9 °C in the first floor and 24.8°C in the ground floor and external average is 25.1 °C. The average percentage of satisfied during summer days is 91% and 89% respectively.

During the summer nights the daytime average temperatures are 24.1 °C in the first floor and 24.5 °C in the ground floor, while daytime external average is 22.8 °C. The average percentage of satisfied during the summer nights is 94% in either case.

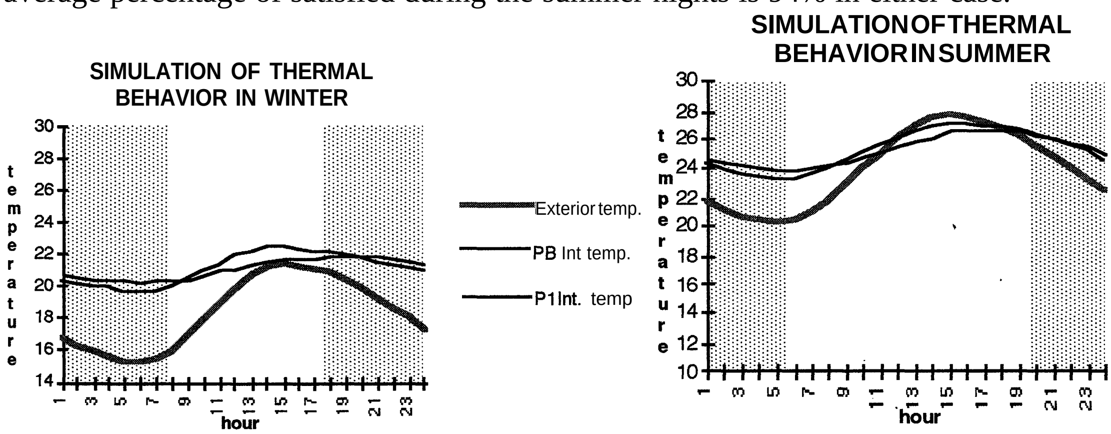

Fig 3 Temperature simulation results in the Tenerife house

3 A bioclimatical house for Tamare, Venezuela: the fourth house

Venezuela is the country with the greatest annual per capita electrical consumption in Latin America. In the Maracaibo lake basin, 40% of electrical consumption is accountable to the commercial and residential sector, and in buildings with air conditioning, about 75% of energy consumption is used to provide mechanical cooling, making this region one of the regions with the greatest per capita energy consumption in America.

The bioclimatic conception, many times perceived as a novelty, is no more than the prolongation of climate adaptive concepts transmitted by individual generations, not architects. Three models of climate sensitive architecture in Maracaibo have existed: the palafitic paraujano building, the colonial-republican building, and the building imported by foreign oil companies. The teachings of these buildings have been forgotten due to the aesthetic popularity of imported styles and cheap energy.

As in the Tenerife building, we propose to integrate architecture with environmental techniques, with improvements on the previous architectural solutions and generating a house which is also adapted to the climatic, social, urban and economic environment of our contemporary cities.

Special importance was given to availability of materials in the eastern coast of the lake of Maracaibo, where Tamare is located, and their environmental characteristics. A steel structure is proposed since steel is used extensively in the oil industry that prevails in this region and much specialized labor is available. Insulating materials are available from the petrochemical industry but do not have a very clean production process.

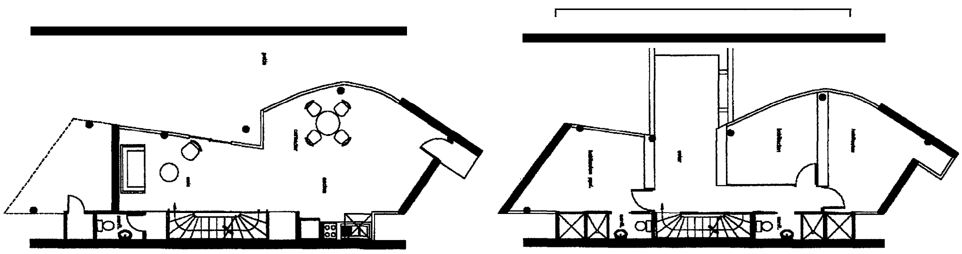

Fig 4 Ground floor and first floor plans of the Tamare House

3.1 Architectural principles

3.1.1 Detached Row Housing

Our proposal for middle income users, in an oil field context near the Lake of Maracaibo, has led us to propose narrow, but rather high, single family units to reduce urban soil consumption and urbanization costs, while at the same time permitting us to perceive the lake horizon. In this situation, where we needed the high density of traditional urban centers in a suburban context, but in an oil culture used to the isolated building, we had to produce a different typology, which could satisfy these apparently contradictory urban and social requirements.

In our proposal, the spaces which characterize an isolated building have been occluded: the backyard and the front garden have been absorbed by the house: the outside has been folded towards the inside. At the same time, the building has been directed upwards and coexists with the exterior, now inside; a channel of light on the side of the property helps to isolate a building that was conceived in a row; thus a typology extracted from the site is born: the detached row house. Thus, the building does not look out onto the street, but rather develops its facade along the band of the patio, contributing, by its curved volumes, to reinforce the feeling of external space.

3.1.2 Horizontal organization of functions in bands

Three bands are organized horizontally: the conditioning band, the conditioned band, and the patio. All the services of the building (kitchen, baths) and the active and passive conditioning systems are located in the conditioning band. The function of this band is to serve the main spaces of the dwelling: bedrooms, family room, dining room, the conditioned band. The patio, is an inner -exterior, lodging vegetation, light and wind. The patio, together with the servant band are responsible for the bioclimatic conditioning of the building. This patio band constitutes another step towards the enrichment of the historical evolution of local patios.

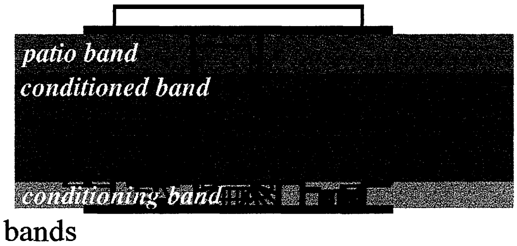

Figure 5 organization in bands

3.2 Bioclimatical techniques and passive systems

Our building increases energy conservation and thermal comfort and uses clean and renewable energy sources to decrease non renewable energy consumption.

In Maracaibo, which has a similar climate data as Tamare, avg. min. Dry Bulb Temperature is 24.7°C, avg. is 27.7°C, avg. max. is 32.9°C, avg. variation is 8°C; avg. Air Velocity is 4.5 m/s, main direction is NE; Avg. max. Relative Humidity is 92%, avg. is 76%, avg. min. is 54%; and avg. yearly precipitation is 490 mm.

Due to extreme climate conditions in the Zulia lake basin, which are even worse in its cities, (thermal islands) our proposal was to design a passive building using natural techniques, mechanical cooling, or both, to reduce energy consumption and approach comfort values. Simulation results show improvements in energy consumption and thermal comfort in all three cases.

3.2.1 Bioclimatical techniques

1. **Shade.** Organization in row houses permits the walls between buildings to be used as shade elements over the facades.
2. **Landscaping** with organic ground cover, and trees, provide lower temperatures around buildings. This cooling effect is not taken into account in thermal simulations, so indoor values could be lower than results indicate.
3. **Precise design of window systems.** Window panes parallel to, the exterior walls are transparent and designed as a window system, which we have called a Matricial Bioclimatic Window, MBW, divided in bands, lines and points, assuming different responsibilities: ventilation, solar protection, natural illumination, visual relations and privacy.
5. **Air movement** is promoted through chimneys, which transfer this air through the living spaces and out to the patio through the MBW. This movement is useful to evacuate hot indoor air, introduce cool air, or achieve comfort by air movement.
6. **Open, shaded, and ventilated indoor floor plans** are proposed, using opaque partitions perpendicular to the servant band and permeable interior partitions perpendicular to these for maximum flow of air.
7. **External finishes in walls and roofs are white.**
8. **Thermal mass** is positioned on the inside of building to reduce thermal oscillations and to work with night cooling. Air cavities for insulation is used in walls, floors and roofs to diminish heat flow by conduction.

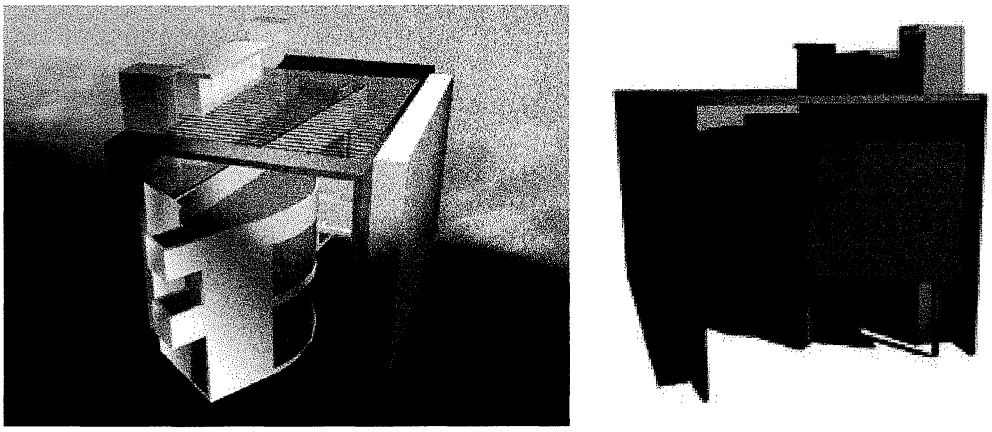

Fig 6 Back and front views of the Tamare House

3.2.2 Passive cooling systems.

1. **Comfort ventilation** by the chimney to the patio, is used to provide direct human comfort by transversal air movement from the chimneys to the patio.
2. **Nocturnal ventilative cooling.** The mass of the building interior is cooled during

the night and then the building is closed during daytime to keep cool air in. When the building is closed electrical fans are used.

3.2.3 Mechanical cooling systems

Air conditioning is proposed as occasionally necessary and useful to cool the building when outdoor conditions are out of the range of passive cooling systems. It can also be used to improve performance of passive bioclimatical systems such as night cooling, which would in this case be mechanical night cooling.

3.2.4 Renewable energy sources

Solar energy is proposed to generate electricity for the electrical fans in the chimney and to heat water for domestic use.

3.3 Thermal simulations

Meteorological data from the urban and airport weather station in Maracaibo was used to analyze thermal performance. Simulations for the worse (May) and best conditions (January) in Maracaibo were carried out. In each case several simulations were done assuming different forms of operating the building which were a combination of opening windows and chimneys to permit flow of air, closing openings to maintain cool air inside combined with fans to achieve comfort and using air conditioning to cool air mechanically.

Two options are shown, the first is opening the building to ventilate from 19:00 to 10:00 hrs and closing it from 10:00 to 16:00 hrs. In this case no mechanical cooling is used, but fans are used to generate air movement for comfort. In January maximum temperatures were generally lower than outdoor values during daytime and significantly lower than the 30 ℃ value recommended by Givoni as the upper limit with which we can achieve comfort with air movement of 2 m/s in developing countries [1]. In May, maximum indoor values reached 33℃ but were still lower than the maximum outdoor.

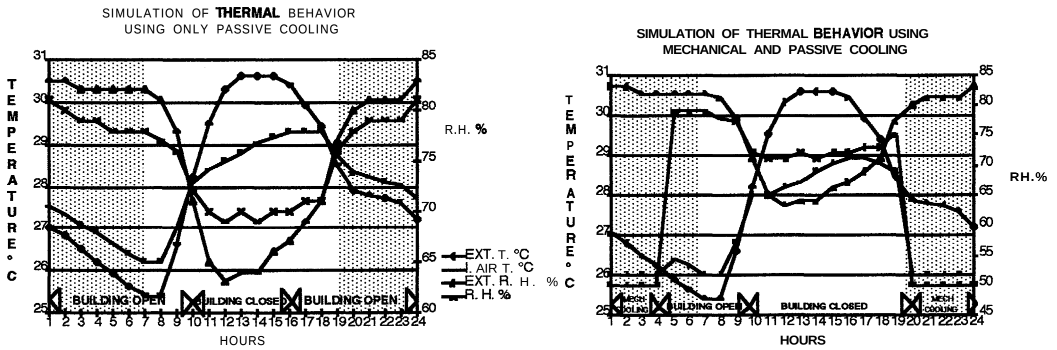

Fig 7 Thermal simulations in the Tamare House

The second option is combining mechanical cooling with passive systems. In this case the building is air conditioned from 20:00 to 4:00 hrs, opened from 4:00 to 10:00 Hrs. and closed from 10:00 to 20:O0. In this simulation indoor temperatures are even lower, never reaching 29 ℃ in January, but reaching 32 ℃ in May. These cases have the disadvantage of high relative humidities (70%) when the building is closed which decreases effectiveness of comfort ventilation.

Other options that have been analyzed are continuos 24 hour cooling, 24 hour natural ventilation and other combinations of closing and air conditioning. All cases provided acceptable results.

Natural illumination values have also been calculated and the averages are between 320 and 210 luxes which are very high compared to necessary standards (100 luxes). There is an adequate distribution of illumination in the spaces, because there isn't a large difference in obtained illumination levels. Uniformity factor is 0.65 which is higher than 0.3 which is the common established limit .

4 House for low income groups in Maracaibo, Venezuela.

This proposal adapts the architectural concepts of the Tamare house, to a proposal for lower income groups. Emphasis is in economy, progressive growth, use of materials found in the site, manufacturing of construction materials by its own dwellers or neighbors, increase of thermal comfort by the use of bioclimatic techniques, and passive cooling systems, and use of materials with low embodied energy. To achieve these objectives manufacturing of soil bricks with a cement content of only 10%, and an artisan elaboration process are proposed. This, together with reduced transportation distances (materials will come from the site) assures an adequate thermal behavior and will reduce environmental pollution. On the other hand, local economy will be improved since brick producers will be members of the community.

5 Conclusion

We think that these two examples demonstrate that it is possible to apply bioclimatical design concepts to an architectural project, avoiding its appearance as an assembly of technological devices. This will increase the possibilities to incorporate bioclimatical devices in new architectural proposals, which will thus have a greater degree of acceptance from its users.

The buildings are expected to be flexible in the management of the sun and the wind, permitting their independent regulation according to comfort requirements and daytime and seasonal variations. The results of simulations demonstrate an adequate application of different bioclimatical techniques and passive cooling systems, for two different climates. However the monitoring of the thermal conditions within the houses, will permit to evaluate with greater precision the behavior of the proposals and the degree of satisfaction of the users with the proposal will be the definitive evaluation of the effectiveness of our proposals.

6 Acknowledgments

We are grateful to Consejo de Desarrollo Cientifico y Humanistico CONDES of the University of Zulia and PDV, the National Oil Company for their grants that have permitted us to develop these research projects. Also to our research assistants L. Rodriguez, M. Moran, N. Soles, R. Fernández, E. Sáez.

7 References

1. Givoni. B. (1994) *Passive and Low Energy Cooling of Buildings.* Van Nostrand Reinhold. New York .
2. Brau, J; Roux, J.J.; Depecker, P. (1987) *Micro-informatique- et comportement thermique des bâtiments en régime dynamique: CODYBA.* Genie Climatique, 11, 15-23 .
3 La Roche, P. (1995) Automated tool for the bioclimatic design of edifications: ASICLIMA. *Technology and Construction. N* 1 l/l P 19-29. Year: 1995.

Projecting Energy Savings from Daylighting in Partitioned Open Plan Spaces

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Abstract

Daylighting has proven to be an important opportunity area for energy savings in buildings in hot and humid climates. Modern office buildings are making increased use of natural light to improve lighting quality while reducing energy costs. A prevalent configuration in office interior spaces is the open plan, which is a configuration of varying-height partitions or panels which are free-standing or integrated into furniture systems. From the viewpoint of lighting, this environment presents a unique opportunity for use of natural light -- mainly because there are no floor to ceiling partitions. In a space with partitions and furniture, illuminance distribution on the work plane is influenced by the inter-reflection and obstructions to which light emitting sources are subjected, creating light attenuation and shadows. Consequently, more accurate daylighting and electric lighting performance data are needed not only for compensating likely light loss but for maximizing energy savings.

This paper presents results of a recent research project that uses scale and computer model measurements to determine lighting performance in partitioned open-plan spaces. Twelve prototypes of interior layout modules in common office buildings were selected for this study. A latitude of 30°N. was selected, typical of the hot and humid areas of the U.S. Results from the evaluation of electric lighting performance show that, on the average, a reduction of 20% was experienced in the partitioned area, compared to the nonpartitioned area. In daytime, the carefully designed features of a multistory office building can successfully permit most of the space to be daylighted and electric lights to be dimmed by a cost effective operated system so that the attenuation can be easily compensated by introduction of daylight. Building energy simulation with measured daylight illumination levels and the performance of lighting control system indicates that daylighting can save over 70 percent of the required energy for general illumination in the perimeter zones through the year. A 25 % of electric energy for cooling may be saved by dimming and turning off the luminaires in the perimeter, zones.

Keywords : Daylighting, Electric Lighting, Energy, Layout, Partition

1. Introduction

A dramatic increase in the design of commercial buildings with daylighting manifests a renewed discovery of the architectural art of glazing as well as an energy-saving feature. Use of daylighting has a strong emotional appeal and numerous studies have' conclusively demonstrated a marked preference for daylight over any other form of lighting. Also, reducing the artificial lighting when natural daylighting is available has economic benefit because lighting accounts for 30-40 percent of the electrical operating costs in commercial buildings or approximately $0. 80/ft^2/year and yet the average commercial building is unoccupied approximately 75 percent of the time. Most lighting professionals, however, have enjoyed the convenience of non-daylit building design, with a constant electric lighting level regardless the. consideration for level of daylight in the space. The practical usefulness of optimal reintroduction of natural light into office perimeter spaces is fulfilled by integration of .the electric lighting with proper luminaire control in a view toward building energy savings. In view of this situation, obviously, what is needed here is the basic daylighting illuminance data and design guidance to utilize both electric illuminance characteristics and daylighting availability of the perimeter layouts with generalized -interior configuration.

The particular emphasis of the study is placed on parametric evaluation of the effects of the representative configuration of partitioned open space on daylight levels, electric lighting design and energy saving in the office building. For this purpose, this study aims to determine the impact of partitioned interior types on the performance of a conventional electric lighting design and to explore the integration method between daylighting, electric lighting, controls and the configuration of partitioned interior on the basis of measured daylighting performance data.

2. Interior layout in modern offices

2.1 Layout options

Most new building designs produce a block-type structure which is well lighted and air conditioned, and which is divided by a few access corridors radiating from the central service core. This type of construction places all or majority of the private offices in the core area and allocates space along the building perimeter for others. This concept arises from the premise that employees performing- routine tasks which keep them at their desks almost entire work day require both the psychological advantages and daylighting benefits of window space. In brief, an office perimeter is typically designed according to three planning options; closed, open, and combination. Each option is distinguished by the proportion of partitioned or enclosed-to-open space that exists in the layout. The open plan is a configuration of varying-height partitions or panels that are free-standing or integrated into furniture systems. This is, perhaps, the most typical planning option in the perimeter spaces of an office building.

2.2 Configuration of partitioned interior space

Working within the open office environment, there are certain basic forms and shapes that the, designer uses to organize and manipulate the interior space. Office layout is often structured by the independent workstations or clustered groupings organized in a variety of unit module of workstations. In the initial investigative stage in this study, accordingly, a procedure to generalize the configurations of typical partitioned space modules have been involved. In modern office, space standards establish geometry and square footage criteria for an individual,' group, organizational function. The inevitable approach probably is to investigate typical configurations of furniture and functions for the interior space. In the layout of partitioned open space, a common design is to place the unit workstation modules in rows. This method will permit the use of bank-type partitions as a divider for those activities which require visual privacy while still obtaining maximum utilization. The unit workstation should face the same direction unless there is a compelling functional reason to do otherwise. Figure 1 illustrates a set of partitioned configuration which can commonly be found in common office buildings.

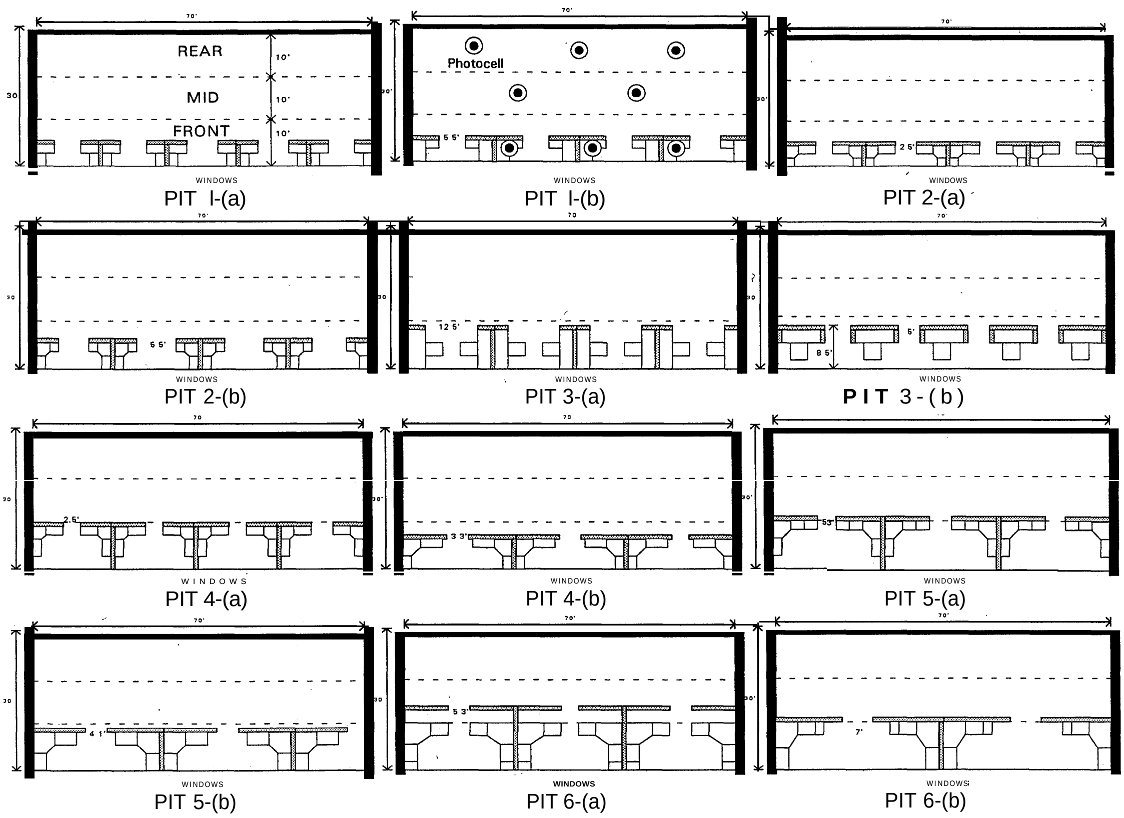


Figure 1. Configurations of partitioned interior type (PIT)

3. Daylighting measurement

3.1 Scale model and data acquisition

With reference to the units partitioned 'space selected previously, a total of 12 partitioned interiors has been established within a perimeter of an office interior measuring 70' (W)x 30' (D) as shown Figure 1. Two ceiling heights, that is, 10' and 12', were considered and a rectangular-shaped window on one wall measuring 68'(W) x 6.5'(H) with 10' high ceiling and 68'(W) x 8.5'(H) with 12' high ceiling were used as the sole sources of daylighting. Also, to 'improve the practical usefulness of the data, two types of shading devices for full and partial shading were applied.

This study is based upon a systematic series of measurements within the sky simulator at Texas A&M University by using an indoor sun simulator and utilizing photometric sensors to read illumination levels. As shown in Figure 1, three different locations - the front, mid, and the rear spaces - were separately considered because each depth of space from the window wall has different reflected sunlighting potentials. The characteristics of each partitioned space type in terms of daylighting performance were determined from the measurements under diffuse sky conditions without sun. This measurement represented the performance results in terms of *Daylight Factor* (DF), a ratio between indoor horizontal illuminance from daylight between exterior horizontal illuminance.

3.2 Daylighting strategies

The evaluation of partition system must be in integration with building envelope system as both daylight admitting system and thermal barrier between interior and outdoor so that the daylighting measurement data can be used in building energy simulation. In this process, optimal building envelope can be inferred for maximized energy saving due to its thermal and lighting properties. A total of 10 different building envelope system types which consist of ceiling height, window size, shading, and ground reflectance are defined as shown in Table 1.

Table 1 Building envelope system types

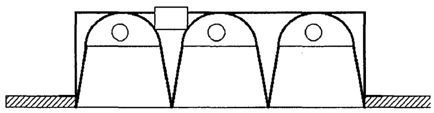
Type	Ceiling height	Window size	Shading	Ground Ref.
BLDG 1	10'	68' x 6.5'	No	20 %
BLDG 2	10'	68' x 6.5'	No	40 %
BLDG 3	10'	68' x 6.5'	Full	20 %
BLDG 4	10'	68' x 6.5'	Full	40 %
BLDG 5	12'	68' x 8.5'	No	20 %
BLDG 6	12'	68' x 8.5'	No	40 %
BLDG 7	12'	68' x 8.5'	Partial	20 %
BLDG 8	12'	68' x 8.5'	Partial	40 %
BLDG 9	12'	68' x 8.5'	Full	20 %
BLDG 10	12'	68' x 8.5'	Full	40 %

4. Artificial lighting design for partitioned interiors

4.1 Selection of lighting fixture

The most important factor in designing of an electric lighting system is the selection of the light source and its layout. Presently, a high percentage of office lighting utilizes fluorescent rapid-start lamps and low efficacy magnetic ballasts. A typical fluorescent lighting system consists of a three-tube fixture with cool white 40W bulbs (F40cw). Parabolic fixtures, which is the selected light source for general illuminance in this study, are linear parabolic troughs with lamps positioned at the focus. These fixtures came into widespread use during the 1970s in offices. Most parabolic fixtures are louvered luminaries with parabolically shaped white or metallic troffers. The louvers are open grids of opaque, semi-translucent, or reflective shielding and diffusing media that collimate down-coming light rays. The specification of the luminaire is described in Table 2.

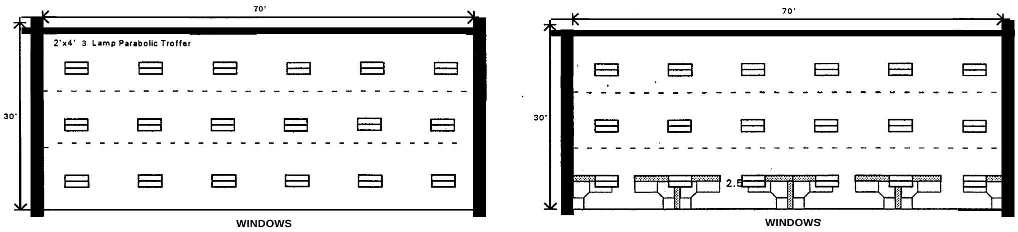
Table 2. Luminaire Description

Description	2’x4’ 3 Lamp Parabolic Troffer
Configuration	
Lamp	Fluorescent (F40cw)
Lamp Watts	40 W
Total Watts	120.0 w

4.2 Electric lighting system design in totally-open interiors

The design of electric lighting system for partitioned open-plan requires additional consideration to compensate for the likely loss of illuminance caused by the vertical obstruction. To estimate the impact of the partition system on general illumination environment, representative partitioned interior types which have been used are selected, and then a conventional approach to design an electric lighting layout is applied for the partitioned space. The impact of the presence of the partition systems is expressed in terms of light reduction by comparing to a totally open plan.

To get an average 50 fc of ambient illumination in a totally open plan, a luminaire layout is proposed on the basis of conventional design method of electric lighting and is illustrated in Figure 2. Eighteen lighting fixtures are asymmetrically arranged forming a 3 by 6 rectangular matrix on the 12-foot high ceiling without suspension. In this 3x6 layout of the luminaries, on the average, a total of 2,196W is required to get an average illuminance of 50 fc and generate a power density of 1.05W/ft^2 for electric lighting only. The layout of the luminaries is also applied to the selected partitioned open-plans so that the impact of the presence of partitions on the electric lighting performance can be estimated in term of light reduction.



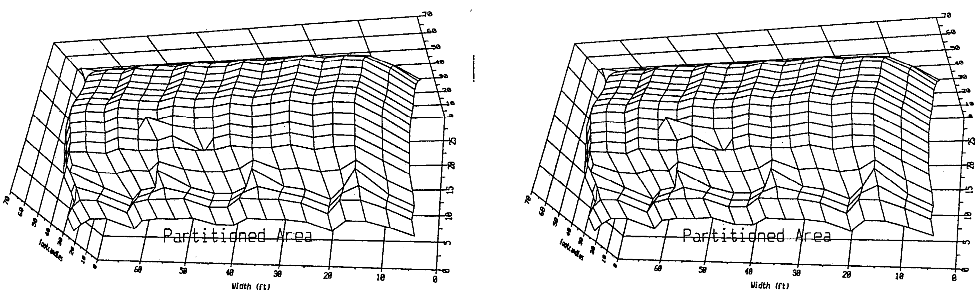
(a) the open-plan (b) a partitioned open-plan (PIT2)

Figure 2. Luminaire Layouts

The performance of the electric system design in totally open interior is calculated by Lumen-Micro 6.03 and the results show that the average, maximum, and minimum level are 54.5, 67.1, and 3 1.5 fc, respectively. In spite of even distribution of the luminaries, some degree of fluctuation with a standard deviation of 6.67 in illuminance level is unavoidable. On the average, in the partitioned interior, a reduction of 4 fc occurred through the whole space but more attenuation is detected around the partition, showing about 15 percent drop, compared to the basecase open plan. Various approaches can be proposed to compensate for the light attenuation.

4.3 Artificial lighting layout for partitioned interiors

It is suggested that the attenuation in light level and the deterioration in qualitative lighting by shadow effect may be mediated by both increasing the number of luminaire , and more dense arrangement of the luminaries on the ceiling in the partitioned open-plan interior. The feasibility test for the implementation is performed by the Lumen-Micro.



(a) PIT 2 (b) PIT 4

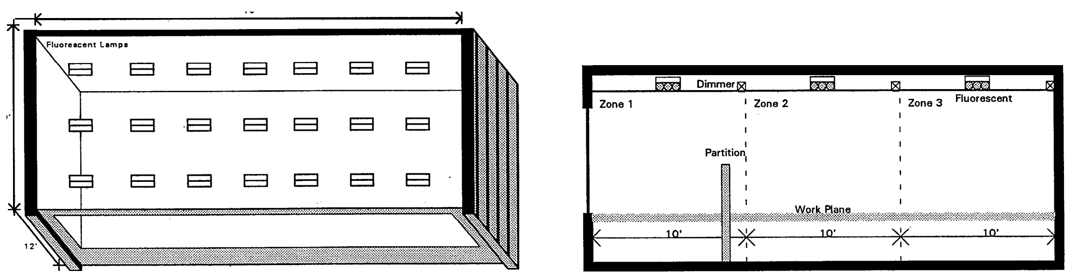
Figure 3. Electric light distribution in partitioned open spaces

As shown on Figure 3, results from the evaluation of electric lighting performance show that, on the average, a reduction of 20% was experienced in the partitioned area, compared to the nonpartitioned area. In order to compensate the attenuation, the electric power density should be increased by 20% to provide more light, resulting in increased number of luminaires. In the building interior model for the study, an extra power density of about $0.25W/ft^2$ is demanded for the partitioned area.

5. Building energy simulation

5.1 Target building plan and lighting layout

Perimeter spaces of an office building typically benefit from daylight. It is assumed that this is a one-story building without an outdoor obstruction. Figure 4 shows the geometry of the one story office space with dimensions of 70'x30'x12'. The luminaire layout provides an average illumination of 60 fc in case of the presence of the partitions as examined before. On the process of energy simulation by the ENERCALC developed in Texas A&M University, a continuous dimming system located at the back of each daylit zone reflects the variation of daylight level in the partitioned spaces.



(a) Building Geometry

(b) Building Section and Controls

Figure 4 Model building and layout of luminaries for energy simulation

5.2 Energy savings due to daylighting

Comparing with the extreme case which has no daylight, on the average, daylight plays a big role in reducing a 25 % of the, annual cooling load and a 70 % of lighting load for general illumination. Figure 5 illustrates the amount of required energy for general illumination in each partitioned space type. In spite of the presence of the various types of partitions, the partitioned open plan has almost same potential to utilize daylight for not only general illumination and but building energy savings. Unless daylight availability of a building is extremely higher than usual, however, other design factors, such as window or outdoor environment must be well incorporated with the interior condition in order to compensate for the blocking effect of the vertical partitions.

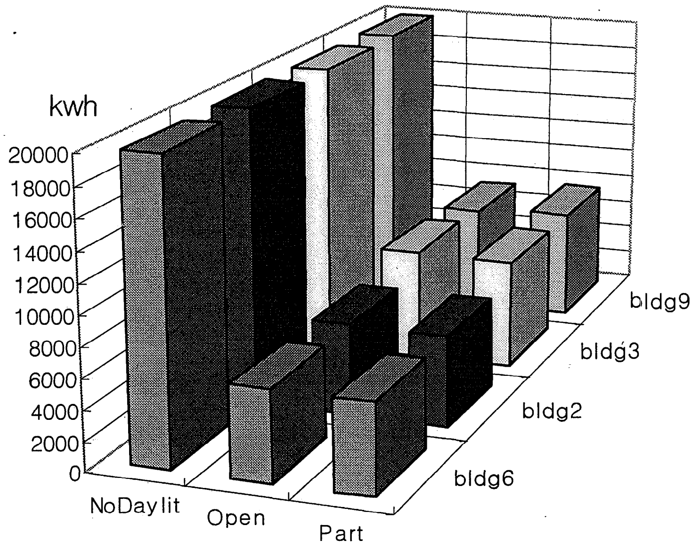


Figure 5 Annual energy consumption for lighting

6. Conclusion

Results from the evaluation of electric lighting performance show that, on the average, a reduction of 20% was experienced in the partitioned area, compared to the nonpartitioned area. In daytime,, the carefully designed features of a multistory office building can successfully permit most of the space to be daylighted and electric lights to be dimmed by a cost effective- operated system so that the attenuation can be easily compensated by introduction of daylight. For the period when daylight is not available, however, the electric power density should be increased by 20% to provide more light, resulting in increased number of luminaires. In the building interior models for the study, an extra power density of about 0.25W/ft^2 is demanded for the partitioned area. The results from building energy simulation with measured daylight illumination levels and the performance of lighting control system indicate that daylighting can save over 70 percent of the required energy for general illumination in the perimeter zones through the year. A 25 % of electric energy for cooling may be saved by dimming and turning off the luminaires in the perimeter zones.

7. Reference

1. Ballman, T.L. and R.E. Leven (Summer 1987) Illumination in Partitioned Space. *Journal of the IES,* , published by IESNA
2. Degelman, Larry, 0. (April 1990) ENERCALC: A Weather and Building Energy Simulation Model Using Fast Hour-by-Hour Algorithms *Proc. The 4th National Conference on Micro-Computer Applications in Energy,* Tucson, ‘AZ.
3. HartKopf, V. and V. Loftness. (1995) Interior Environmental Systems for an Intelligent Building. *Proc. International Symposium on Intelligent Buildings,* Yonsei University, Seoul, Korea

Moisture control in buildings - How can varying outdoor climate be allowed for when designing the structure?

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Abstract
This paper describes the general need for secure protection against moisture, and methods for designing the structure in this respect. Ensuring that all the possible moisture loads on different parts of the building have been systematically considered creates the right conditions for designing structures without moisture problems.

An important part of the work of designing structures to deal with moisture loads is to estimate the risk of damage and problems resulting from random variations in the properties of materials, indoor and outdoor climate and user/occupant habits. This paper describes, in particular, the effect of a varying outdoor climate and methods for allowing for it when calculating the moisture conditions of various parts of a building.

By performing calculations for a number of cases over many years (196 14990) and by studying the spread of the results from one year to another, it is possible to identify the reference (average) year and the most severe (extreme) year. With this information, appropriate safety factors for design calculations can be determined. The paper describes calculated moisture conditions and presents examples of design safety factors for different moisture problems encountered in different types of designs.
Keywords: calculation, climate, design, moisture, random, safety

1 The need for improved moisture protection

There is general agreement today that a dry building process and dry structures are important factors in producing healthy buildings. In addition, we know that, in many cases, moisture is the cause of poor durability and limited life of materials and structures. **This** means that controlling and restricting moisture content, and providing means of guarding against the inconveniences and damage caused by moisture (moisture control), are important. Good moisture control can be achieved only through good design.

Moisture control through appropriate design is needed both for new buildings and for repair/maintenance. Such work will predominate in Sweden for some years into the future, and particular attention must be paid to determining the methodology so that it becomes a useful aid for the work.

Moisture control through design applies not only to the actual design work and how the structure is to be arranged: it must also consider conditions during the construction and use stage. The designer (or someone else having the appropriate authority and overview of the whole) must be able to specify constructional details and methods and limitations to be observed during use.

2 Designing for moisture resistance

Moisture control through appropriate design relates to the elements of the building process intended to ensure that the building is not damaged, or its users inconvenienced, whether directly or indirectly, by moisture. Figure 1 is a schematic illustration of the components of such moisture control through design.

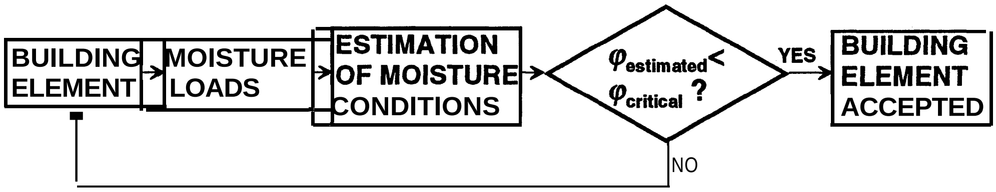

Figure 1. Simplified diagram of the various components of moisture control through design.

Moisture control through appropriate design considers each part of the building and its associated details separately. All the necessary input information on the characteristics and dimensions of the materials for each part of the building is collected. We also need to assess the types of damage that could occur and decide on acceptable levels of risk of damage and inconvenience.

Internal and external moisture loads for the particular part of the building need to be carefully determined. External climate loads can be determined from meteorological data.

Calculations, experience or other aids can then be employed to calculate or assess the expected moisture loads, which can then be compared with critical values. This part of the work can vary widely, ranging from meticulous computer calculation of expected spatial and temporal moisture loads to a brief observation that some particular material is insensitive to moisture, with the result that the expected moisture load is therefore uninteresting.

If this systematic consideration of the moisture load on the various parts of the building shows that the expected risks of moisture damage or inconvenience are acceptable, then moisture control through design can be regarded as completed. However, if unacceptable risks are identified, the design details need to be changed, or it may be necessary to specify special building conditions or impose restrictions on use.

3 Risk and safety philosophy

An important aspect of moisture control through design is the matter of safety factors and the safety philosophy. Material properties, climate and user habits all vary randomly, and forecast moisture conditions or loads cannot be expressed as hard and fast values but as probabilities of their occurrence. This probability can then be set against the risk of certain damage or inconvenience occurring.

This paper discusses methods of allowing for the stochastic variations in outdoor climate in the process of moisture control through design. For this purpose, material properties, user habits and other factors that can vary are assumed to be known and constant, although in a complete moisture design process they would have to be considered in the same way as variations in the outdoor climate.

There are a number of different ways in which allowance for these variations can be made:

- ***Determination of the frequency function*** of the particular moisture condition. This requires the moisture conditions to be worked out on an hour-by-hour (or day-by-day or month-by-month) basis over a very long period of years of natural climate variations - in principle, for as long a period as the life of the building. The risk of a particular moisture condition arising can then easily be read off. This method requires an excessive work input. In addition, it requires climate data for past years to be used as a forecast for future years, which means that it cannot consider long-term climate variations.
- ***The extreme value method.*** See figure 2A. This involves calculating moisture conditions resulting from an extreme outdoor climate, e.g. the worst that has occurred in a 50-year period. This value (which in this example can be assumed simplified to carry a 2 % risk) is then used to compare with the critical values. In addition to the availability of a large quantity of climatic data, the method also requires an understanding of which climate conditions are most unfavourable for various types of moisture damage. However, there is no need for an additional safety factor, as this is already incorporated through selection of the extreme climatic condition..
- ***The normal value method.*** See figure 2B. This involves calculation of the moisture conditions on the basis of normal (reference) outdoor climate values. This data can be taken from that for a single real year, regarded as typical of several years, or can be a postulated year, known as a Test Reference Year (TRY). The values of moisture conditions calculated in this way must be corrected in some way, $\Delta\varphi$, *in* order to

represent an extreme year. The advantage of this method is that it is quite easy to obtain data for a normal year, although a drawback is that the necessary corrections for moisture conditions depend on the type of moisture damage and on the type of climate.

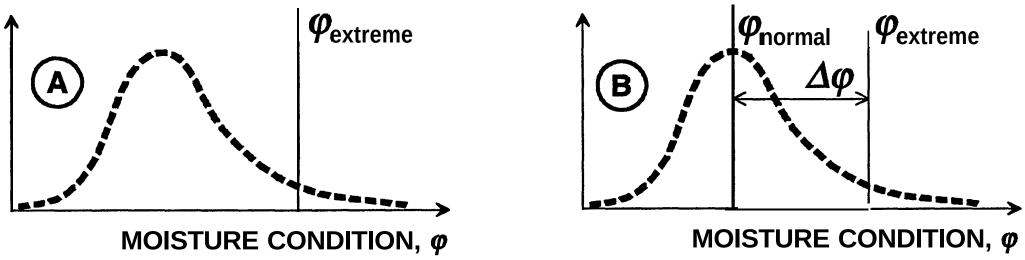

Figure 2. Frequency curves for moisture conditions. φ is used here as a general designator of a moisture condition that can be relative humidity, moisture content, moisture ratio, capillary saturation etc. A illustrates the extreme value method, by which an extreme moisture condition is calculated from data for extreme climatic conditions. B illustrates the normal value method, by which the extreme moisture condition is obtained by applying a correction ($\Delta\varphi$) to the normal (reference) value of moisture condition.

A research project being carried out at the Lund Institute of Technology [1] is intended to describe methods of determining the most unfavourable moisture condition that will occur during the lifetime of a building. Suitable corrections for converting the reference year conditions to those of an extreme year are being developed by investigating how moisture conditions vary from one year to another. By comparing calculated results for many years (30 years), it is possible to identify the most unfavourable year. A correction for the variations in climatic data is then determined as the difference between the moisture conditions for the most unfavourable year and those for the reference year. This correction can be applied either in the form of a multiplying factor or as an absolute addition. The method is illustrated by examples in Sections 4 and 5.

4 The drying-out potential

In certain cases, the maximum permissible moisture input to indoor air (v_{FT} in kg/m^3) can be described using the drying-out potential, known as the II-factor [2]. This factor describes the mean value of the difference between the saturated vapour concentration of the external surface, v,(T) and the vapour concentration in the outdoor air, v_e. A condition for drying out is that $v,(T) > v_i$ i.e. that $v,(T) > v_e + v_{FT}$, from which we obtain the condition $v_{FT} <$ II.

The mean value of the Π factor between times t_a and t_b is

$$\Pi = \frac{1}{t_b - t_a} \cdot \int_{t_a}^{t_b} \left(v_s(T) - v_e \right) dt \qquad (1)$$

The temperature, ***T*, is** an equivalent temperature which allows not only for the air temperature but also for solar radiation or for both solar and long-wave radiation. This example is for a horizontal roof and the effect of snow on the roof has been ignored.

Taking the climatic data for Bromma, near Stockholm, and calculating a **Π** factor for each year, we obtain the result shown in Figure 3. The mean values of **4,5** and **2,7 g/m³** respectively are shown by the solid lines in the diagram.

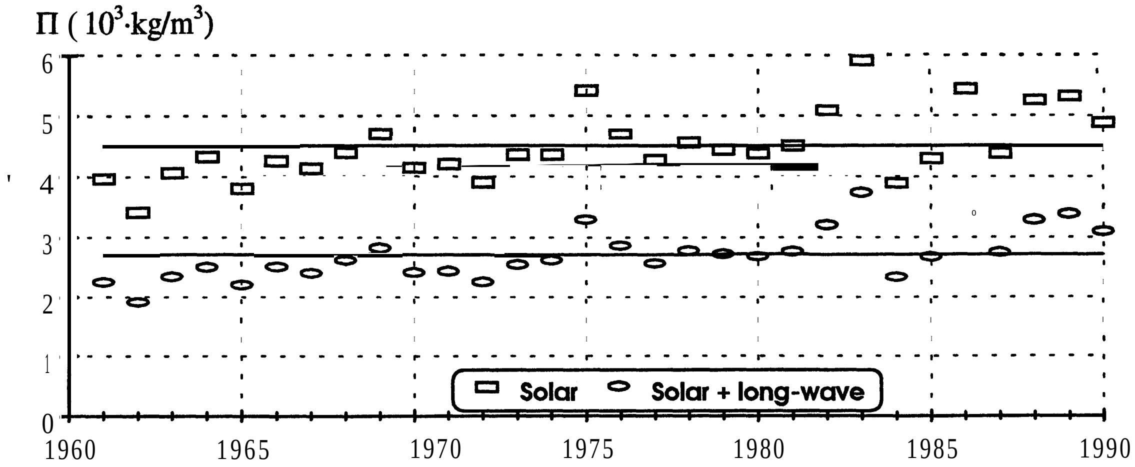

Figure 3. Variation in drying-out potential for a horizontal roof in Bromma with allowance for solar radiation and for solar radiation plus long-wave radiation.

The year that most closely agrees with the mean value is referred to as the Mean Deviation Year (MDY) and used as the reference year. The concept of MDY presupposes that the moisture conditions can be characterised by a value for each specific year. The MDY and the extreme year are normally different for different types of moisture conditions and structures. In Figure 3, the **MDYs** are 1981 and 1979 respectively. The difference in the **Π** factor (**ΔΠ**) between the most unfavourable year (the extreme year) and MDY is the correction needed for conversion of a result for a reference year to that for an extreme year.

ΔΠ can be expressed either by a term or by a factor:

$$\text{AI-I} = \Pi_{ext} - \Pi_{ref} \tag{2}$$

or

$$k_\Pi = \frac{\Pi_{ext}}{\Pi_{ref}};\ \Delta\Pi = k_\Pi \cdot \Pi_{ref} - \Pi_{ref} = \Pi_{ref} \cdot (k_\Pi - 1) \tag{3}$$

As the most unfavourable year in this example is that with the lowest **Π** factor, **ΔΠ** is negative and $k_\Pi < 1$. In the example shown in Figure 3, with solar plus long-wave radiation, the most unfavourable year is 1962 and we obtain: $\Delta\Pi = -0{,}8$ and $k_\Pi = 0{,}7$.

The postulated path in a moisture design is that the designer starts by calculating the moisture conditions for the reference year and then applies an absolute correction or multiplies by a correction factor to obtain values for the extreme year:

$$\Pi_{ext} = \Pi_{ref} + \Delta\Pi \quad \text{or} \quad \Pi_{ext} = k_{\Pi} \cdot \Pi_{ref} \tag{4}$$

In order to be able to do this, the designer needs to know the reference year and suitable values of absolute correction or correction factor. The research project mentioned above is developing methods of determining suitable reference years, absolute corrections and correction factors. As, in principle, each type of moisture condition, structural design and geographical region has its own reference year, absolute corrections and correction terms, it will be a long time before we have all the necessary information. However, the work has revealed certain patterns, which can lead to some general recommendations: see [1] for more details.

5 Summer condensation

The calculations use a computer model for transient calculations of the combined air, moisture and heat transport in one dimension **[3].** The model is based on the method of finite differences, with explicit forward difference in time. Compared with the original version, a number of modifications have been made:

- Several years of real climate data are used in the modified version, instead of data for a single year as used by the original version. This means that moisture and temperature conditions can be calculated for a range of years, e.g. from 1961 to 1990.
- Moisture transport has been complemented by simple equations for the effect of driving rain.
- The vapour permeability has been changed from a constant value to a function of the relative humidity.

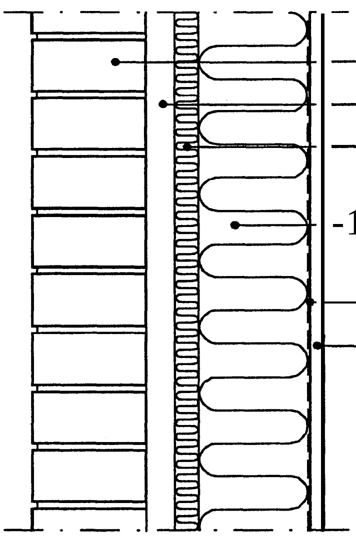

Figure 4. A section through the cavity wall.

The design selected is a cavity wall, and is shown in Figure 4. The effect of the cavity has been neglected. The wall has also been assumed to be completely airtight, and the effect of moisture convection has been ignored. Details of the material properties and calculations can be found in [l].

The meteorological data is that for 1961 to 1990 for Ronneby, in south-east Sweden. Moisture conditions for the reference year (MDY) and for the extreme year, together with the corrections for variation in climate data, are described.

The example calculates the percentage number of cases having relative humidities of 100 %, $f^{\varphi=100}$, in the thermal insulation immediately outside the vapour barrier. This phenomenon of condensation on the outside of the vapour barrier is usually referred to as summer condensation. It occurs when the sun warms up damp brickwork and vapour transport occurs from the outside inwards, rather than the normal transport from the inside outwards. Figure *5* shows the theoretical results for different directions of the wall for MDY and for the extreme year.

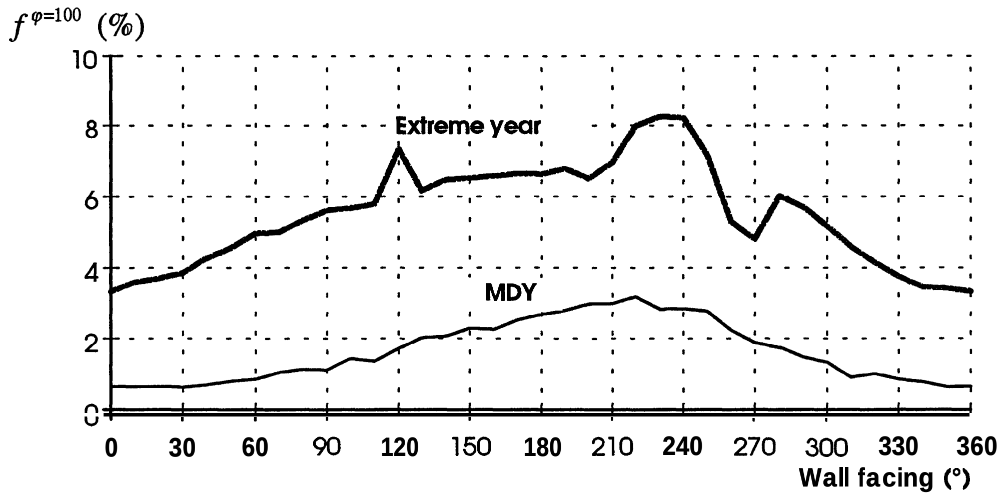

Figure 5. Calculated values of $f^{\varphi=100}$ in the thermal insulation on the outside of the vapour barrier for all directions of the wall in Ronneby, for MDY and the extreme year. North is represented by 0°.

The difference in $f^{\varphi=100}$ can be expressed either by a term:

$$\Delta f^{\varphi=100} = f_{ext}^{\varphi=100} - f_{\mathrm{MDY}}^{\varphi=100} \quad (5)$$

or by a factor:

$$k_{f(\varphi=100)} = \frac{f_{ext}^{\varphi=100}}{f_{MDY}^{\varphi=100}} \quad (6)$$

The value of the correction term or factor varies for the different external directions. If we calculate the corrections as a mean value for all directions, we obtain 3,9 % and 4,1 respectively. If we use the calculated values of $f^{\varphi=100}$ for MDY and apply the above values for correction term and correction factor to calculate $f^{\varphi=100}$, we obtain the results as shown in Figure 6, from which it can be seen that the best agreement is obtained when using a correction term. In addition, this gives the best estimate of the extreme year for those external directions with the highest loadings. In southern Sweden, driving rain comes mainly from the south-west, with the effects of sunshine also being the greatest in this direction, which explains the differences between the different directions as shown in Figure 6.

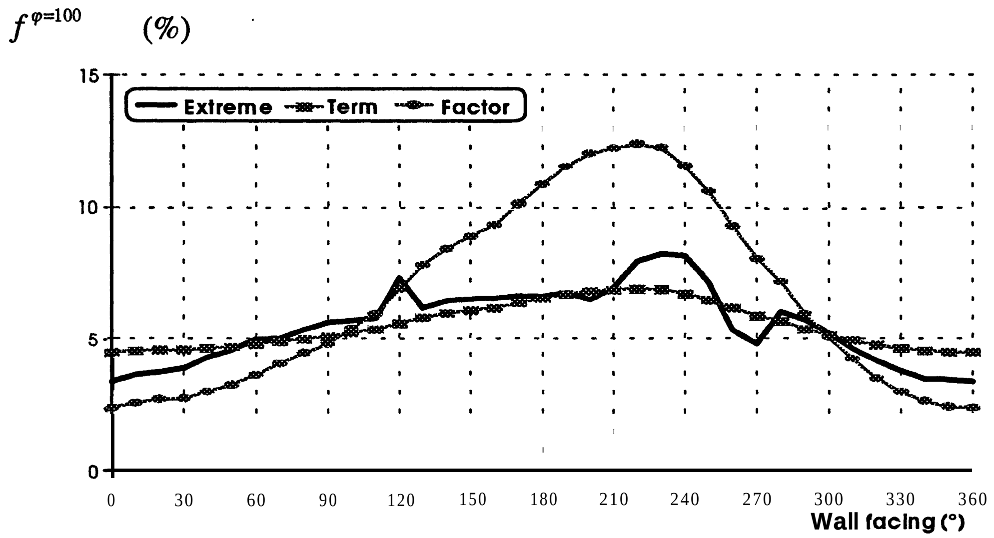

Figure 6. Calculated values of $f_{ext}^{\varphi=100}$, using real weather data, reference years and constant correction term or correction factor respectively.

6 Conclusions

The examples show that the variation in climate from one year to another can give considerable differences in calculated results. Design can allow for the effects of extreme years by using a reference year and then correcting the result. Each type of moisture condition and structure requires knowledge of the reference year and the correction. An absolute (incremental) correction term is more suitable in some cases, and a (multiplying) correction factor is more suitable in others. This paper has described various ways of arriving at this knowledge.

7 References

1. Harder-up, E. (1998) ***Metoder att välja korrektioner vid fuktberäkningar med variabelt utomhusklimat.*** (In Swedish). PhD thesis under publication. Lund Institute of Technology, Building Physics, Lund.
2. Hagentoft, C-E (1994) ***Indoor climate classes. The use of Π-factor.*** Report TVBH-7170, Lund Institute of Technology, Building Physics, Lund.
3. Hagentoft, C-E, (1993) ***Simplified analysis of combined heat, moisture and air transport for one-dimensional cases.*** Report TVBH-7146, Lund Institute of Technology, Building Physics, Lund.

The self-contained dwelling

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Abstract

The Fourth House is a bioclimatic proposal that improves the three bioclimatic and historic models existing in the region The Maracaibo Lake: the indigenous model or *palafito* (the first model), the colonial-republican house (the second model) and the "oil company" dwellings (the third model). The Fourth House is a contained dwelling composed of inhabited objects and a vertical patio, wrapped by a bioclimatic and secure container. The container and the patio work together to create habitable objects. The envelope is the most important element to consider in the design process of bioclimatic sensible bulidings, because of the heat losses and gains throught it. In intertropical latitudes and extremely hot and humid climates, like the Maracaibo lake basin. The elements of the envelope may protect and isolate the interior space from the sun, without cutting the breeze: this is the container's role.

The container is the result of a "two folded" process, both material and inmaterial.

The material fold is opaque and heavy; its climatic responsabilities concern the protection from solar radiation; it also works as a partition wall, as structural support and as a space of services. It's composed of three main bioclimatics elements:

- the *Rampart* -a thick services wall-, responsible for the protection of horizontal plans in the inhabited objects, conducting the breeze, previously cooled by evaporative cooling inside the objects;
- the *Ying-Yang ground-floor* composed by an inorganic ribbon to keep interior temperatures at low value, and an organic ribbon to minimize the reflection of solar radiation and cool outdoor air;
- the Green *Wall* responsible for protection of vertical plans in the inhabited objects, ınd of conducting and cooling the breeze lengthwise, which has both a physical and sychological effect.

The inmaterial fold is permeable and light; its climatic responsabilities concern the otection from solar radiation, regulating ligthing and ventilation. It's composed of o main bioclimatics elements:

- the *Bioclimatic Geometrical* Roof defined by heliosurfaces, protecting from solar iation, and generating electricity and hot water, wind points, collecting the breeze natural ventilation of the inhabited objects, and green lines, protecting from solar ation by an evaporative-transpiration process, and regulating light by filtering, and ilation;
- the *Threshold* responsible for regulating light and ventilation; it defines the entries contained dwelling; a vertical frame works for security purposes.

ywords: Bioclimatic container design, natural ventilation, solar radiation.

1 Introduction

In intertropical latitudes with hot humid climate, such as Venezuela,. building envelopes must reduce influence of solar radiation, and in these, roofs and windows must receive special attention. A bioclimatical house for Tamare, Venezuela, is proposed. This building incorporates design principles from traditional indigenous, colonial-republican and oil company houses in the Maracaibo lake basin to generate a new prototype adapted to contemporary urban third world problems.

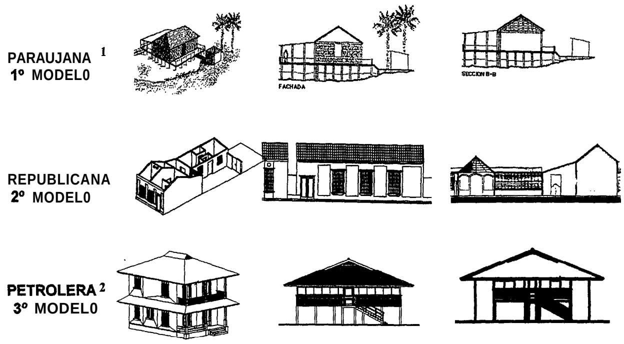
In this paper we will discuss our proposal for the container system, which we have called *BC,* a *Bioclimatic Container.* BC has been designed as a system of elements with specialized functions, assuming different bioclimatic responsibilities. In the first part we will review the evolution of the envelopes in the three previous bioclimatic models; in the second part we will explain the bioclimatic techniques incorporated to the BC in the context of a bioclimatic dwelling, called the Fourth House. Simulations of the bioclimatic behaviour of the Fourth House and preliminary evaluations of BC have been carried out and the results are shown in this paper.

2 From a bioclimatic envelope to a bioclimatic container

Three previous bioclimatic models have been developed in Zulia, the most important oil producing state in Venezuela: the traditional indigenous house or *palafito* (the first model), the colonial-republican house (the second model) and the oil company house (the third model). These models proposed three different bioclimatic envelopes (figure 1).

2.1 The envelope in the traditional indigenous house

The zulian traditional indigenous house or *palafito* is really an inhabited filter; the different components of the envelope -floors, walls and ceilings- are permeable; sunlight, wind, dust and water are regulated by these three components. The floor, built with cane poles, permits the presence of the lake inside of the house; the floor becomes thick. The walls are a big flat filter regulating illumination, radiation and wind; they are walls-celosias in wich other windows are included but with different responsibilities. The ceiling, thick and built in rush -enea thatch-, permits the house to breathe, evacuating the heat, but impeding the rain to penetrate. The rush -palm leaves- is a light and insulating material that doesn’t store heat nor transmits it to the inside.



Sources: [1], [2].

Figure 1: The three previous bioclimatic models existing in the region of the Maracaibo lake.

2.2 The envelope in the colonial-republican house

The Maracaibo colonial-republican houses were built between the second half of the XIXth century and the first decades of the XXth century, and is the legitimate heiress of the main architectural and bioclimatic principles of the Spanish colonial house. It's a rectangular house in a row house arrangement, with a lateral courtyard; it has only one colored facade, with a high door accompanied with one, two or three high and thick windows.The roof has a double inclination towards the street and the patio; it's covered with clay tiles supported by a wooden structure resting on relatively thick walls, built with a mortar of clay and soil contained by cane poles, generally called *bahareque.*

2.3 The envelope in the oil company house

The architecture of the oil company house has inhereted large roofs and eaves. Its development lasted more or less four decades (1920-1960), and is the result of the experience of dutch, british and american transnational corporations experience in the housing sector for tropical areas. Each house is an isolated rectangle, completely surrounded by gardens, most often with four white façades, with its windows and doors protected by a large eave. The roof has a slope in four directions, covered with thin zinc sheets and a suporting wooden or metal structure; the outside enclosures are wooden with an air chamber. The floors are also wooden, that resemble a movable platform.

3 The Fourth House: a bioclimatic container

3.1 The Fourth House

The <u>Fourth House</u> has been conceived as an isolated house but inside a system of row houses in an effort to reduce the cost of urbanisation and the consumption of urban land. The <u>Fourth House</u> deals with the apparent contradiction existing between rationalising urbanisation costs and considering the specific urbanisation way of life. The spaces of the isolated house have been occluded: the backyard and the front porch have been absorbed by the house like the removable little tables in an airplane: the outside has been folded towards the inside. The house becomes vertical and lives in parallel with the occluded exterior; wrapped by a bioclimatic container; the container and the patio work together to create habitable objects (figure 2).

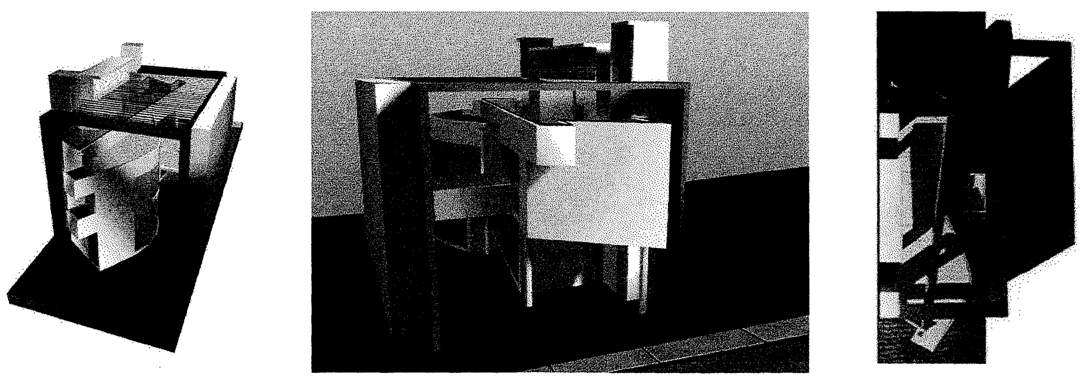


Figure 2: The Fourth House: a new bioclimatic model.

The Fourth House is organized in three bands: the *conditioning*, the *conditioned* and the *patio*.

In the *conditioning band* the passive conditioning systems are installed (eolic chimney) as well as the active systems and the service area (kitchen and bathrooms).The function of this band is to serve, conditioning, the main spaces of the dwelling: dormitories, living, dining, the *conditioned band*.

The *patio band* is an inner exterior, lodging the vegetation, the light and the wind. The *patio* and the *conditioning bands* are responsible for the bioclimatic conditioning of the house. Additionaly, the *patio band* is one more step in the enrichment of the historical evolution of the outside of houses.

3.2 The Bioclimatic Container, BC

The container is the result of a “two folded” process, both material and immaterial. The material fold comes from the land; the inmaterial fold, from the sky (figure 3).

The material fold is opaque and heavy; its climatic responsibilities concern the protection from solar radiation; it also works as a partition wall, structural support and services. It’s composed of three main bioclimatics elements:

- the *Rampart* -a thick services wall-, responsible for the protection of horizontal plans in the inhabited objects, conducting the breeze inside of the objects, previously cooled by evaporative cooling;
- the *Ying-Yang ground-floor* composed by an inorganic ribbon to keep interior temperature at low value, and an organic ribbon to minimize the reflection of solar radiation and cooling the outdoor air;
- the *Green Wall* responsible of protecting vertical plans in the inhabited objects, conducting and cooling the breeze lengthwise, which has both a physical and psychological effect.

The inmaterial fold is permeable and light; its climatic responsibilities concern the protection from solar radiation, regulating ligth and ventilation; it also works for security purposes and landscape visuals. It’s composed of two main bioclimatics elements:

- the *Bioclimatic Geometrical Roof* defined by:

heliosurfaces, protecting from solar radiation the roof of the objects and its openings, and generating electricity and hot water; they are thin to avoid storing heat, and built with oferrocemento; they support a photovoltaic system and solar collectors; the photovoltaic cells (11.2m^2) generates 960w, enough to activate the air extractors installed in the eolic chimneys and to illuminate the tresholds; the solar collectors (8m^2) produces enough energy to heat a 4001iter reservoir;

wind points or eolic chimneys, collecting the breeze for natural ventilation of the inhabited objects; are white and built with insulating material; they work together with the green lines, which help to lower the air temperature; and

green lines, protecting from solar radiation by an evaporative-transpiration process, and regulating light by filtering, and ventilation; they are really a wire cable structure, covered with a green surface controlling solar radiation through absortion, reflection and transmission, lowering air temperature through evapotranspiration;

- the *Threshold* responsible for regulating light and ventilation; it defines the entries to the contained dwelling; a vertical frame works for security purposes and landscape visuals.

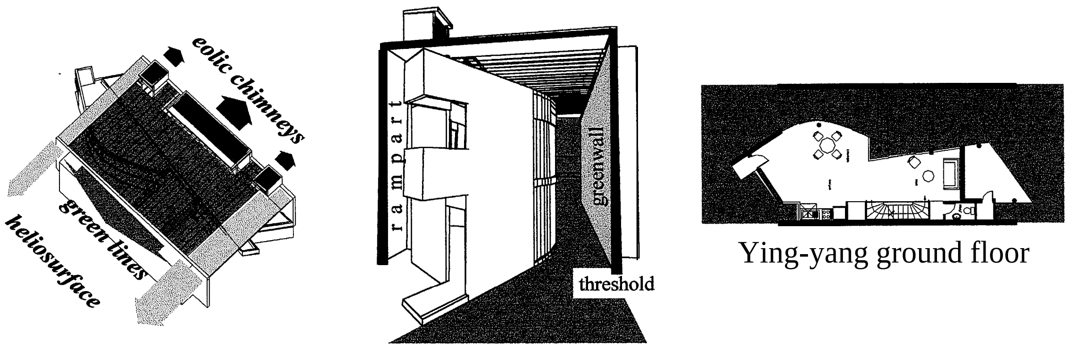


Figure 3: The Bioclimatic Container.

3.2.1 Thermal evaluation

In order to determine the efficiency of the container we analysed two buildings, one with the container and the other without the container, using the meteorological data of the station based in Maracaibo's international airport.

The average values of the last ten years were plotted in a psychrometric chart, in order to examine the relationships between the comfort ventilation zone and the design strategies. The results showed for the whole year that the daily values were inside of the comfort ventilation zone, excepting at noon and at the beginning of the afternoon, when they were located in the mechanical cooling and conventional dehumidification zone.

The study was carried out with the CASAMO-CLIM program [3]; we simulated best (January) and worst (August) climatic conditions, considering the internal charges generated by a family of four people, home appliance equipment and home lights.

The comfort data used to determine the index of satisfied people taken as reference, was a maximum comfort temperature of 30°C with a wind speed of 2m/s as was proposed by Givoni [4] for developing countries.

For the analysis we also assumed three different building operation alternatives:

- opening windows and eolic chimneys to permit air movement;
- closing the openings in the morning to maintain low night temperatures and moving the air with fans for comfort, and opening windows and eolic chimneys at night to permit air movement;
- using mechanical cooling at differents times of the day.

3.2.1.1 Results

The simulations carried out have shown for the best alternative, that the bioclimatic container can lower the inside temperature 4°C, in relation to outdoor temperature. The presence of the container diminish in all the alternatives the difference between maximum and minimum temperatures. The results of the analysis are shown summarized in table 1 and figures 4 to 8.

		January			August		
		with container	without container		with container	without container	
alternatives		*a*	*b*	*b/a*	c	*d*	*d/c*
I ***Building opened 24 hours at day***	.(**1)** temperature averages (°C)	27.19	27.64		28.77	28.97	
	maximum temperature (°C)		.+2,65			.+1,75	
	minimum temperature (°C)	.+0,48			.+1,02		
	comfort index	*0*	0.66		0	0.84	
II Building closed in the morning and opened at night	.(2) temperature averages (°C)	25.95	28.28		27.67	30.01	
	maximum temperature (°C)		.+7,46			.+7,15	
	minimum temperature (°C)	.+0,76			.+0,64		
	comfort index	*0*	0.81		0	1.16	
III Building using mechanical coolingfrom 8am to 6pm, and opening the building at night	.(3) temperature averages (°C)	25.55	25.89		26.49	26.01	
	maximum temperature (°C)		.+1,35			.+0,46	
	minimum temperature (°C)	.+0,8 1			.+0,56		
	energy consumption (kwh)	4.48	27.32	6.1	12.3	34.75	2.8
IV ***Building using mechanical coolingfrom 9pm to dam, and closing the building during the rest of the dav***	.(4) temperature averages (°C)	26.93	28.69		27.3 1	29.73	
	maximum temperature (°C)		.+6,68			.+7,20	
	minimum temperature (°C)	.+1,43			.+0,27		
	energy consumption (kwh)	7.76	5.32	0.7	13.24	12.36	0.9
V ***Building using mechanical coolig 24 hours at dav***	energy consumption (kwh)	12.29	30	2.4	19.75	41.6	2.1

Notes: exterior average temperature: 26.90 (January), 28.51 (August)

.(1) with a ventilation ratio of 30 changes/hour in daytime;

.(2) with a ventilation ratio of 30 changes/hour in night-time and 1change/hour in daytime;

.(3) using air conditioning in daytime to provide 26°C temperature and a ventilation ratio of 30 changes/hour in night-time, to provide nocturnal convective cooling;

.(4) closing the house in daytime with 1 change/hour.

Table 1: Thermal evaluation of the Bioclimatic Container.

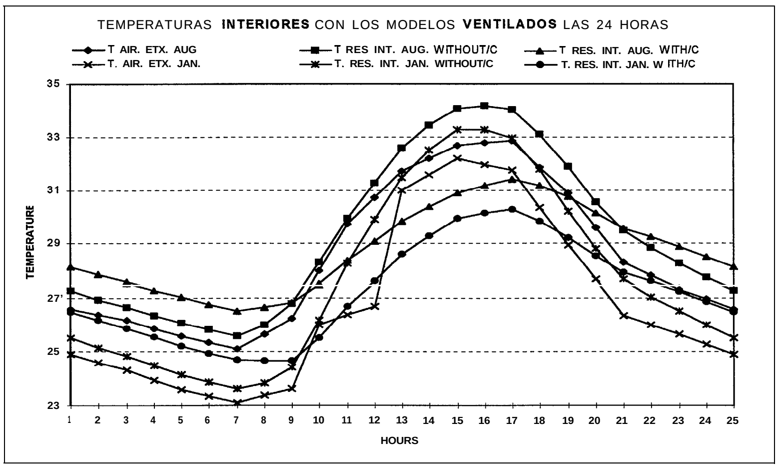


Figure 4: The inside temperatures in both models natural ventilated 24 hours at day.

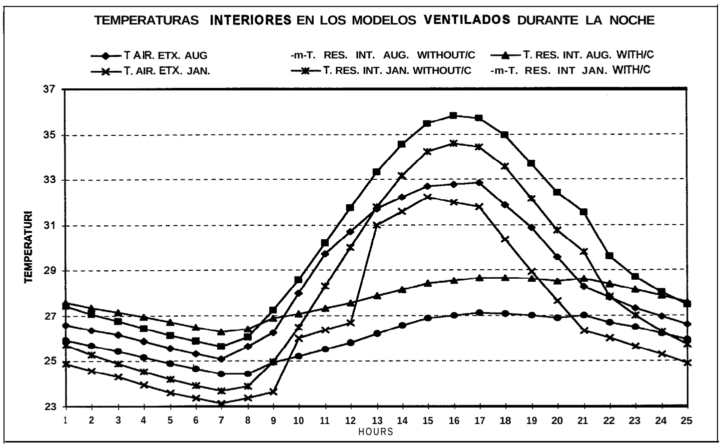


Figure 5: The inside temperatures in both models ventilating at night.

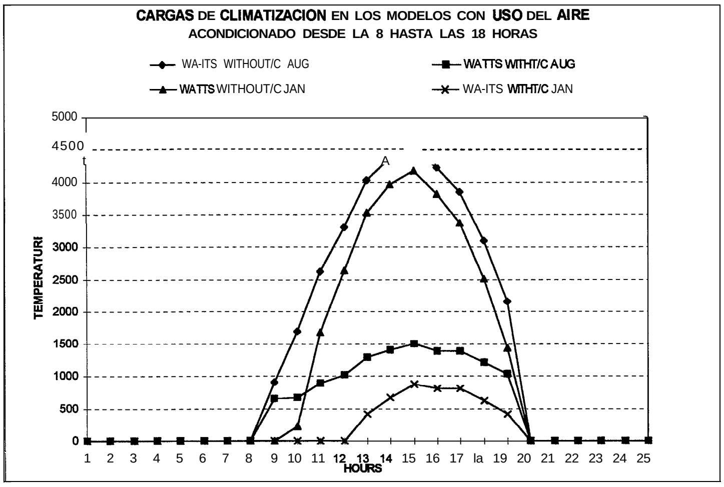


Figure 6: Conditioning charges in both models using mechanical cooling from 8am to 6pm.

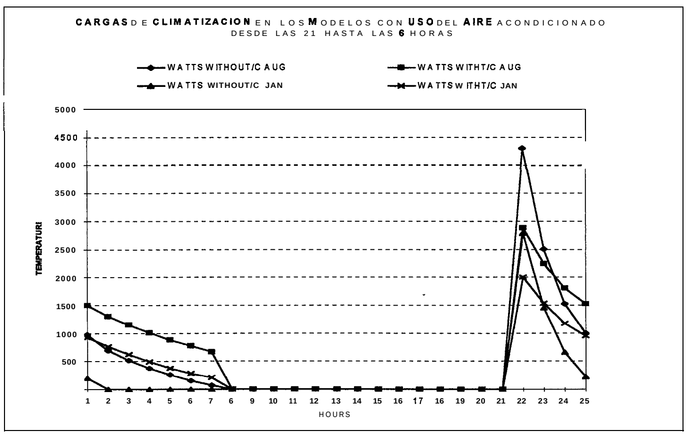


Figure 7: Conditioning charges in both models using mechanical cooling from 8am to 6pm.

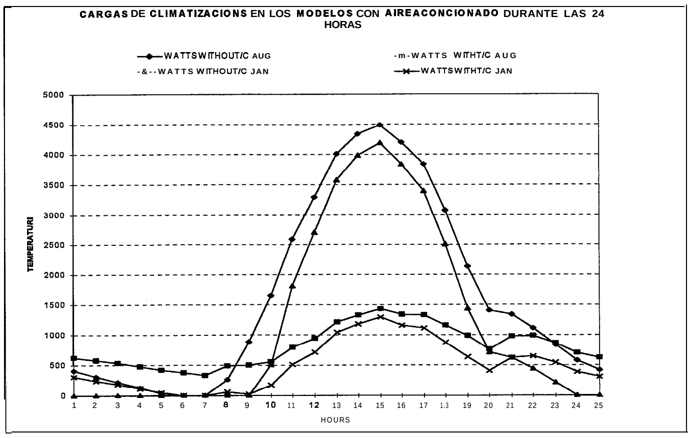


Figure 8: The inside temperatures in both models using mechanical cooling during 24 hours at day.

4 Conclusions

According to the simulations outputs, we determined the effectiveness of the model with the container to diminish air temperature and maintain thermal inside of the house, and also to diminish the climatization energy charges, in spite of registering a higher energy consumption in the mechanical cooling alternative from the 9pm to 6am: anyway, Maracaibo's psychrometric chart shows that the mechanical cooling is required at noon and at the beginning of the afternoon, while at night-time we can be in comfort using only natural ventilation.

The review of the three bioclimatical envelope models existing in the region has permitted the development of a new model: the BC, that incorporates the experience of the three previous models, integrating contemporary technology with tradition. The palafitic notion of *filtering envelope*, the *thick envelope* of the colonial-republican house and the *hat envelope* of the oil company house have been considered and reformulated in the Fourth House -a self contained house-, creating a bioclimatic container with low technology, improving the inside comfort.

5 References

1 Garcia, A. (1997), El espacio primigenio, *IX Conferencia Internacional sobre Conservacidn de Centros Históricos y del Patrimonio Edificado*, Valladolid, 7-11 julio, pp.25-35.
2 Romero, P. (1997), *La arquitectura del petróleo*, Ediciones Lagoven, Caracas.
3 Campana, D., Watremez, *G.* (1990), *CASAMO-CLIM: Manuel d'utilisation,* ADEME Service Formation, Paris, 88pp.
4 Givoni. B. (1994), *Passive and Low Energy Cooling of Buildings,* Van Nostrand Reinhold, New York, 263pp.

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A graphic method to evaluate shading effectiveness in windows and facades

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Abstract
The shading effectiveness of solar protections is determined by the percentual comparison of the shade area projected in the opening or facade, in relation to the total area of the unprotected window or facade. This study proposes a graphic tool to quantify the efficiency of solar control strategies of the openings and building facades for the shade elements proposed in an intertropical locality, in order to establish suitable prototypes according to different orientations.

The shading masks that are used for the evaluation and design of solar protection systems, permits to obtain a value, which would indicate its effectiveness, due to the fact that projections from shade devices obtained from the sunpaths in the celestial vault, don't correspond for all the points of the opening; but generally for the middle point (50% effectiveness) and or extremes of the base of the window (100% effectiveness).

Considering the limitations mentioned above, the shadow effectiveness protactor is proposed, which is based on the principles of the shading masks applied to multiple reference points obtained in the opening or facade surface, with an established percentage. **Taking** as starting point the shading mask of each prototype, effectiveness isolines were drawn (from 0 to 100%), through which the sunshine conditions of the window or facade for any moment of the day and year can quickly be determined.

The shadow effectiveness protactor for openings or facades constitutes a tool that permits its direct application in the design of buildings since it uses a solar diagram as base point, which is very common in the studies of insolation in architecture. The instrument can be as accurate as is required, through the incorporation of reference lines corresponding to intermediate percentages of effectiveness and it is also applicable in cases located in any latitude, using the appropiate solar chart.
Keywords: Solar control, building envelope, energy in buildings, thermal comfort, design tools.

1 Introduction

The effectiveness of the solar protections from the point of view of the shading of the openings and of the facades of the buildings, is intimately related to its efficiency in the control of the incidence of the direct solar radiation. This is determined by the comparison among the area of projected shadows on the window or facade surface considered by the solar protection devices, with respect to the total area of the window or unprotected facade, expressed in the form of index or of percentage [1]. The average of the hourly amounts obtained for a given direction, corresponds to the effectiveness of the system for the stipulated date.

The calculation of the factors and or percentages of shading effectiveness with a high degree of precision, can be by an analytical or graphical method, through numerical processing in worksheets, graph simulation of the shadow paterns in facade and the calculation of the shadowed area in the opening produced by the solar protection through Autocad or other computerized programs elaborated for such means, such as CODYBA version 5.0 [2]. Other programs exist in the market, such as AutoVision, Accurender, ArchiCad, 3D StudioVis, etc. that permit to accomplish the simulation of the effects of the insolation, but don't permit the quantification of the efficiency of the shade elements.

The calculation of the effectiveness of a solar control device as compared to the direct solar radiation, using tabular data and / or the drawing of the standards of the shading, is dificult, laborious and slow that escapes to the ordinary labor of the architect. Considering these disadvantages and limitations, together with the inavailability in tropical developing countries, of specialized programs that permit these calculations, in this work is presented a versatile graph tool: the effectiveness shading protactor. This is based on the representation principle of the shade masks of the solar obstructions and permmits to determine the percentage of effectiveness in an single reading and with sufficient approximation for any direction, hour and date of the year, reasons by which it can be of great usefulness for the architectect and engineer. These effectiveness protactors, are used in an analogous way to the graphs used to determine the shadow angles and direct solar radiation for facades [3].

2. Methodology

2.1 Determination of effectiveness isolines on the surface of the opening or facade.

The isolines of effectiveness constitute geometric places of the points of the surface of the opening that have the same percentage of efficiency shading before the existence of a given solar obstruction. These lines are obtained as the representation from a series of shadows generated by the protective element on the surface of the window, which are characterized by having the same coverage area, taking as reference the shadow projected by the ends of the protection, in frontal vertical projection view.

The isolines are fictitious path lines of the shadows projected by the ends of the element of solar control that correspond to a given percentage of effectiveness. In the case of an overhang, the equal efficiency lines constitute parabolic configuration curves whose extreme points superior (A) and inferior (B) define respectively, a square or rectangular shadow - according to the proportions of the opening- and triangular areas which are equivalent to the percentage of stipulated window surface covered. The intermediate points of the isolines generate a series of shadows in a trapezoidal shape equivalent in surface area, which can be traced through the use of computer drawing programs of great precision such as Autocad. See Figure 1.

It is important to point out that the shadows that are projected outside of the opening (B'), but whose address coincides with one of the inferior extreme points of the opening (B), will always generate the same form and dimension of the shadow on the surface of the window. See Figure 1. In this case, the reference will be the frontal vertical shadow angle that defines that plane that contains all the solar beams that divide the window according to the stipulated proportion.

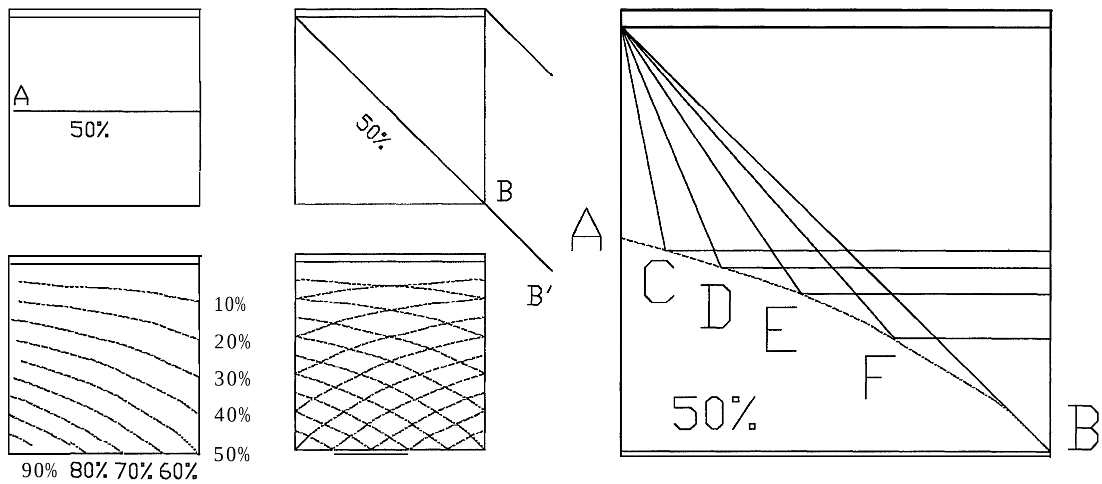

Figure 1.- Determination of the effectiveness isolines generated by a horizontal shade element for an opening

What is previously explained in the representation of the isolines of effectiveness for the particular case of the openings is valid in application to other scales, as in the case of the facades of the building, where solar protection devices exist or adjacent architectural volumes exist that generate shadows, such as is shown in Figure 2.

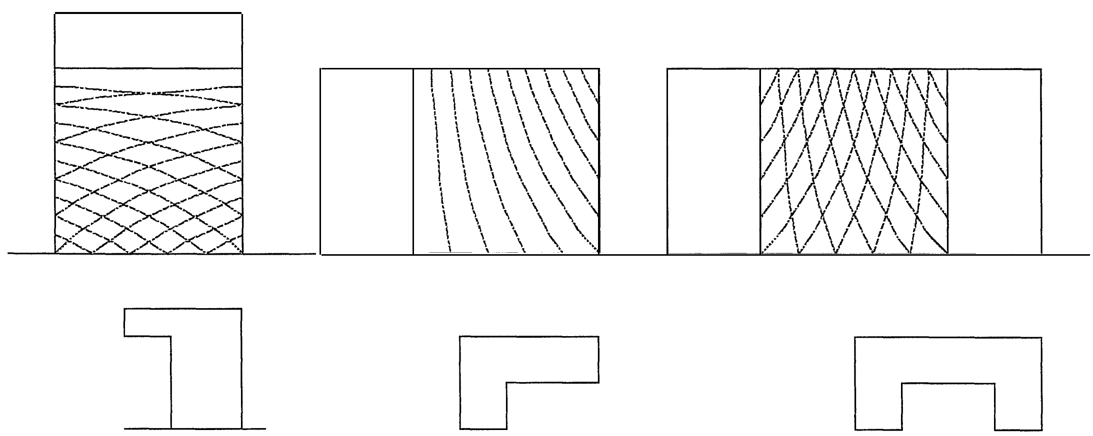

Figure 2.- Isolines of shadow effectiveness generated by superior and lateral volumes that project shadows on the surface of the facades

2.2 Geometric spatial - conception of the shadow effectiveness protactor.
The shading masks of the solar protection systems traditionally are built projecting toward the celestial vault opaque devices of one (< 100% effectiveness) or two points of view (100% of effectiveness) located in the extreme inferior of the opening that will be protected [4]. In our case, to determine the hemispheric projection of the isolines of effectiveness - obtained in the shadow receiving surfaces -, it is required to determine several observation points located on each one of the equal effectiveness lines, as of those which are traced visuals taking as direction the extreme(s) of the solar protection until it intersects with the celestial sphere. Thereinafter, the celestial isolines obtained to be projected stereografically on the horizon plane, generate the effectiveness protactor for the shading.

This graphic protactor constitutes a multiple projection system of solar protections obtained from the celestial vault from each one of the points that describes the different isolines. In this process, several series are obtained from superposed shading masks which upon joining them, generate at the same time, isolines that permit to establish the percentage of protection effectiveness of the opening or in its defect, the percentage of direct solar radiation that the surface of the opening receives for the stipulated solar protection, according to the established ranges (for example, increases of 10%).

In the case of overhangs, the system of isolines traced on the protactor generates a structure in concentric and symmetrical form. The lowest levels of effectiveness in the projection of the shadow, responds to an almost semicircular curve that when it goes through the lengthening and compressing processes the efficiency range is increased until defining a rectiline (for 100%). In the case of vertical elements it adopts a predominantly radial and symmetrical structure, except for the isolines of the highest levels of those which effectiveness become semiconcentrics. See Figure 3.

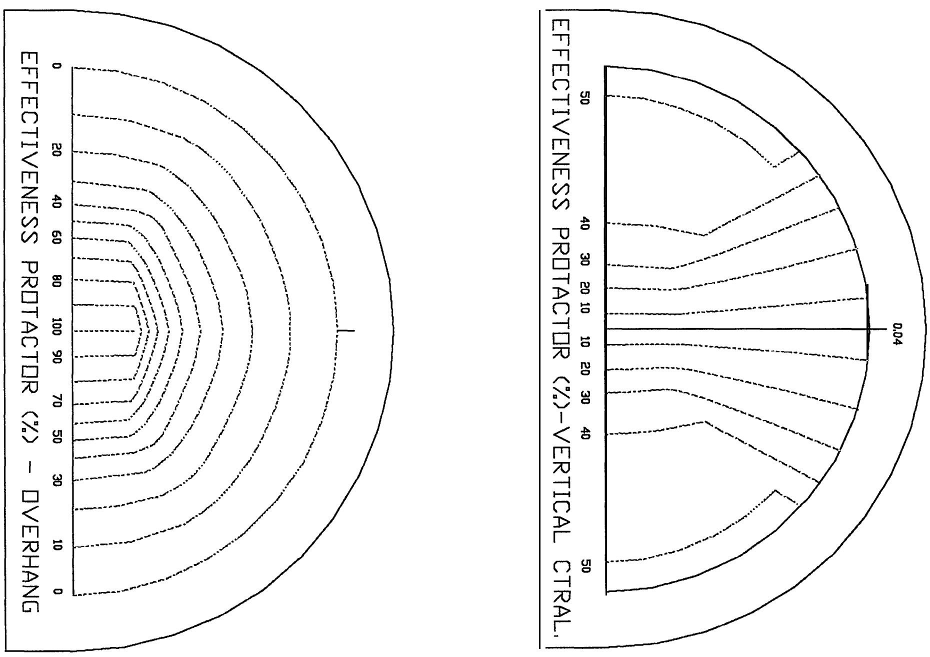

Figure 3.- Effectiveness protactor for a horizontal (left) and a vertical central solar protection (right) equivalent to the 50% of the surface of a squared configuration window.

2.3. **Tracing of the effectiveness protactor from the analytical calculation of the points of the isolines.**

Continuing the previous considerations and appealing to the principles of trigonometry applied to the incident solar beam and to the shadow generated by the extreme points of the protective element, the coordinates of a fictitious sun whose apparent movement will describe in facade the isoline corresponding to the percentage of stipulated effectiveness can be determined, in function of the solar altitude angles and of the horizontal shadow angle. With these two coordinates can be established the position of the apparent sun in the celestial vault and the shadow thrown by one of the extremes of the solar protection element. In Figures 4 and 5 are illustrated the different angles and dimensions to consider in the case of an overhang and a vertical device in a central position.

Using equations that result from applying spherical and flat trigonometry to the solar beam, taking as reference the corresponding plans of the horizon of the place[5], of the facade of the building [6] and of the solar protection, can be obtained the intermediate reference points (C, D, E, F...) that permit the tracing of the isoline on the window as well as in the protactor. The coordinate system of each point is defined by frontal, lateral and horizontal angles of shadow and the solar incidence angle on the facade. See Figures 4 to 6.

Below are presented the data and the analytical expressions that were used for the setup of the worksheets of the angles and projected shades.(See the nomenclature at the end of the work)

2.3.1. Data:

g, B, As, HSA

2.3.2. Unknown:

1) For horizontal shade elements:

$$d = g / \cos HSA \qquad (1)$$

$$xs = d \text{ sen } HSA \qquad (2)$$

$$b = B - xs \qquad (3)$$

$$ys = 2A / (B + b) \qquad (4)$$

2) For vertical shade Elements:

$$d = g / \cos HSA \qquad (1)$$

$$b = 2 As / (g + \text{sen } HSA - B) \qquad (5)$$

$$ys = B - b \qquad (6)$$

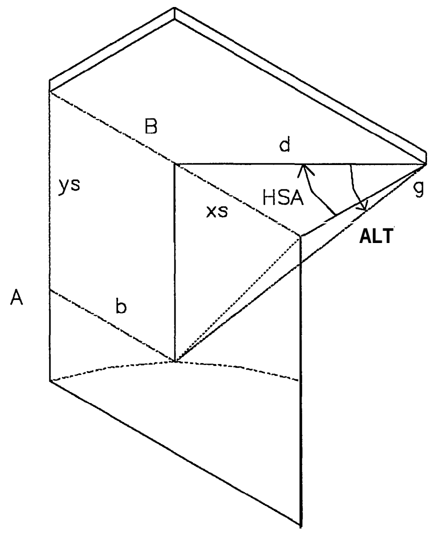

Figure 4.- Angle relationships among the solar horizontal protection elements and the shadows projected in the surface of the window.

3) For isolines representation:

ALT = Atan (ys / d) (7)

FSA = Atan (cos ALT sen HSA) (8)

FSACAD = 180º + FSA (9)
(if FSA is negative)

FSACAD = 360" - FSA (10)
(if FSA is positive)

INC = Acos (cos HSA cos ALT) (11)

S = g tan INC (12)

4) For protactor isolines representation:

LSA = Atan (tan ALT cos HSA) (13)

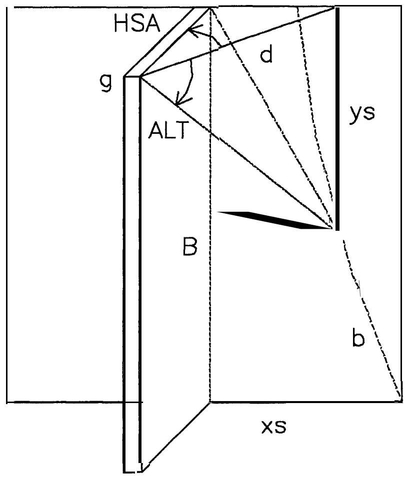

Figure 5.- Angle relationships among the solar vertical protection elements and the shadows projected in the surface of the window

In the cases of solar protections that are located in a central position on the surface of the opening, as in the prototype of a vertical element, we will consider within the shadow area to calculate, the thickness of the same protection element that, in the case of the overhangs, was not taken into account by virtue of the fact that they were located outside of the surface of the window. Because of this, for example, in the vertical protection the horizontal extreme shade for an effectiveness of 50% will not divide exactly by half the openings to protect, but at a smaller distance; while for an extreme oblique shadow in the order of 50%, generates a trapezoidal configuration instead of triangular. See figure 7.

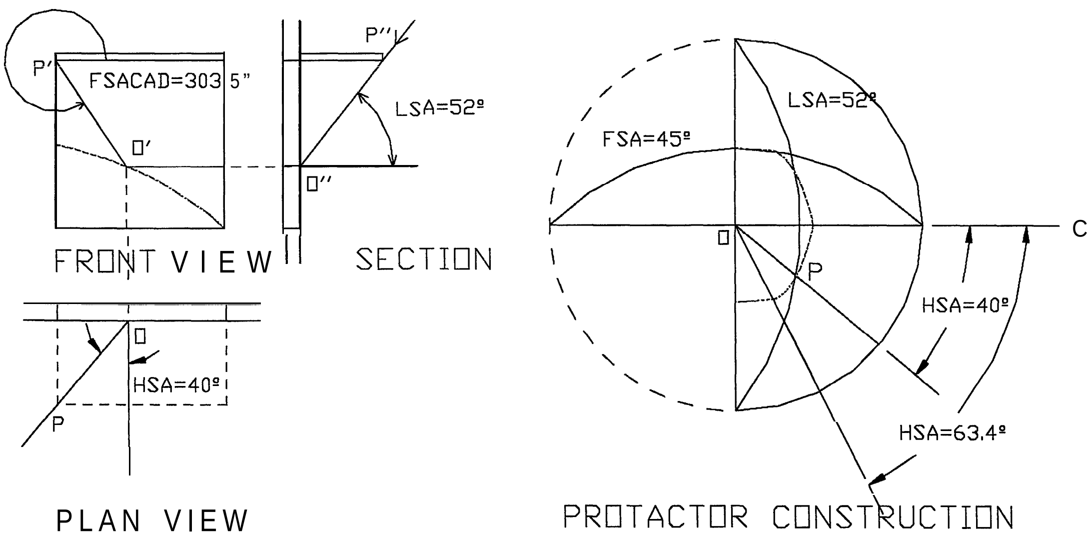

Figure 6.- Required shadow angles and traced of the isolines in the effectiveness protactor.

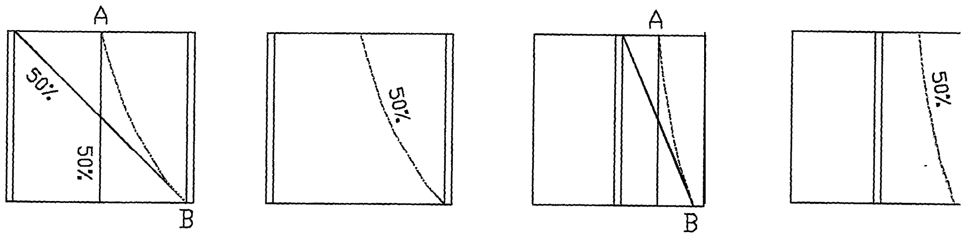

Figure 7.- Effectiveness isolines in the shading of the opening for a central and lateral vertical protections.

3 Discussion

It is evident that for each solar protection system to consider, there will exist a design for its respective effectiveness protactor, something which supposes a moderately laborious task, compared with the simulation method graph. Once its representation is obtained, it will permit the evaluation of infinite cases attending any direction of the window, hour, date of the year and latitude (using the corresponding solar diagram).

Because in Autocad, the representation process graph and the calculation is very slow, for the elaboration of the effectiveness protactor manually, a computerized program designed for this will be required, handling the Lisp language, in the same Cad package.

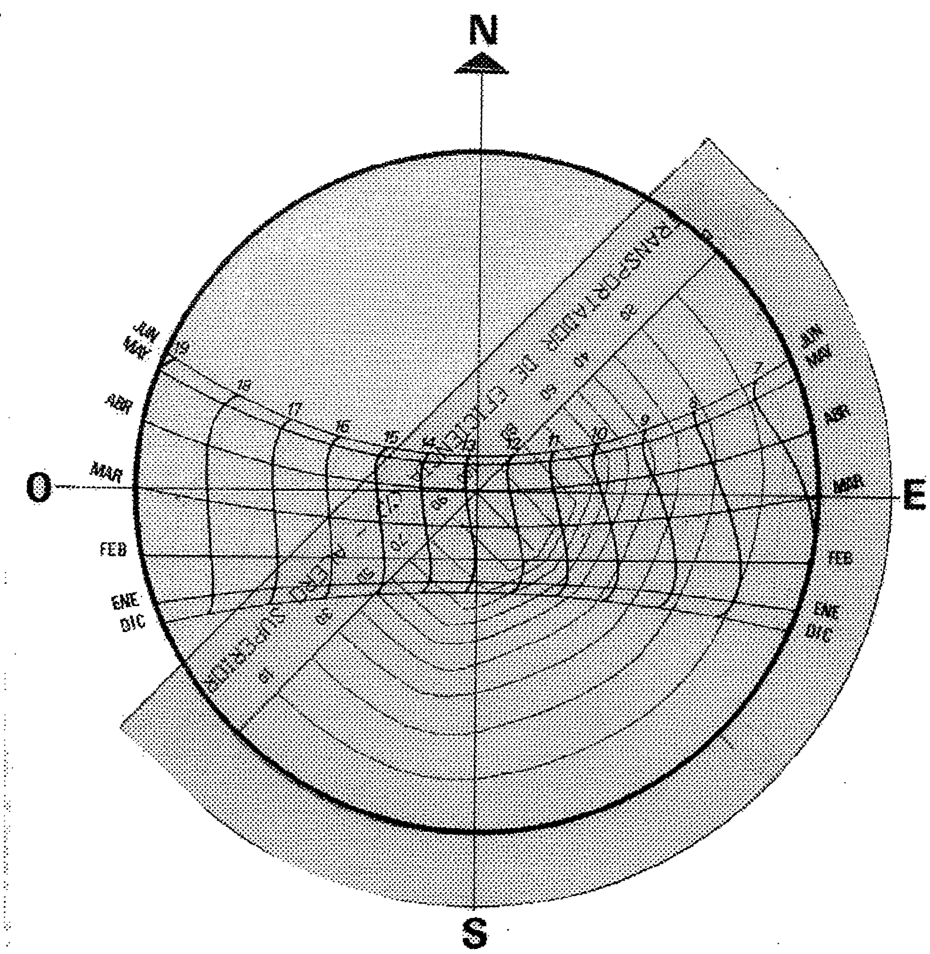

Figure 8.- Assembly of the effectiveness protactor with the stereographic solar graph for the study of an opening with direction southeast.

4 Conclusions

l)The effectiveness protactor in the openings shading constitutes a tool that permits its direct application in the architectural design since it uses as base a solar diagram, very common in the studies of insolation.

2) The overlapping of the isolines of the protactor with the reference lines for the different apparent solar paths, permits to quantify with good approximation the value of the hourly effectiveness of a solar protector. See Figure 8

3) These tools can be applied in scale models, to evaluate the insolation conditions in facades and or roofs, two-dimensional devices of solar protection for facades, or volumetric studies for the purpose of shading.

5 Acknowledgements

To the Consejo de Desarrollo Científico y Humanístico (CONDES) of La Universidad del Zulia by the financing of the research project "Control of thermal gain in the openings of the buildings" , of which is extracted the present paper.

6 Nomenclature

g	Depth of horizontal or vertical shade element
B	Horizontal dimension of the opening (overhang case) or vertical dimension of the window (vertical fin case)
As	Area of the projected shadow
HSA	Horizontal shadow angle
ALT	Solar altitude angle
FSA	Frontal vertical shadow angle
FSACAD	Frontal vertical shadow angle according to Autocad convention
LSA	Lateral vertical shadow angle
INC	Solar incidence angle
S	Length of the projected shadow for the segment g of solar protection

7 References

1. Rivero, R. (1967) *Parasoles I – Estudio comparativo de la eficacia de los parasoles fijos ante la radiación solar,* Servicio de climatologia aplicada a la arquitectura, Universidad de La Republica, Montevideo.
2. De Oteiza, P., Gonzalez, E., Hinz, E. And *Quirks, C.* (1986) *Proyecto Clima y Arquitectura,* Editorial Gustavo Gili, Mexico.
3. Brau, J., Krauss, *G.* And Roux J.J. (1992) *CODYBA – Cahier des algorithmes*, Centre de Thermique de I'NSA de Lyon (CETHIL), Laboratoire Equipement de l'Habitat, Lyon.
4. Olgyay, V. And Olgyay, A. (1976) *Solar Control and Shading Devices,* Princeton University, Princeton.
5. Rivero, R. (1972) *Asoleamiento en Arquitectura,* Servicio de climatologia aplicada a la arquitectura, Universidad de La Republica, Montevideo.
6. Szokolay, S.V. (1983) *Arquitectura Solar*, Editorial Blame, Barcelona (España).

Moisture, mold and health in apartment homes

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Abstract

The prevalence of observations of moisture or mold was surveyed in 240 apartments and the health status of the occupants was surveyed with a questionnaire. A random sample of 120 apartment buildings were taken from the building registers of three cities. The buildings and two apartments from each were carefully walked through and all the signs of moisture and mold recorded. The occupants of the apartments and the house manager were also interviewed for their observations and the damage and repair history of the building. The field study was made using questionnaires and checking lists by civil engineers, trained for the standardized procedure. Before the visit of the surveyor, a health questionnaire was sent to the occupants of the apartments studied. In 60% of the apartments, signs of current or previous moisture damage could be observed. Part of the faults had been repaired, but 42% of the apartments were assessed to be in need of repair because of the moisture observations. Signs of moisture were observed in nearly all the facilities in common use (97%). Respiratory symptoms, such as cough, nocturnal cough and dyspnea, sore throat, hoarseness, rhinitis, nasal bleeding and impaired sense of smell were significantly associated with the observations of moisture, as well as sinusitis (OR=2.58). When the exposure was defined as mold present (either visible mold or odor of mold), the association was significant for several symptoms and respiratory infections:common cold, sinusitis and bronchitis. The results show the health-based importance of good maintenance.
Keywords: Apartement house, moisture,mold, exposure, health effects

1 Introduction

Many factors can lower the air quality in homes. Typical sources for indoor air pollution are tobacco smoking (respirable particles, CO, VOC), gas stoves (NO, , CO) or woodstoves and fireplaces (CO, PAH). Also building materials (formaldehyde, radon), earth underlying the home (radon) and moist materials and surfaces (biological agents) can lower the indoor air quality [1]. Dampness, condensation or moisture causing permanent or intermittent wetting of materials may cause growth of molds, bacteria and rot fungi. In buildings, this microbial growth may damage buildings and lower the quality of indoor air.

The principal factors causing dampness can be leaks in ceilings, walls, windows, roofs or piping. Also lack of design or work, wrong construction methods, aging of materials and heat leak may cause moisture damages in buildings [2]. Dampness and mold growth in dwellings have been associated to a number of respiratory health effects [3],[4]. Since excess moisture in structure is the main factor which permits growth of these microorganism, observations of dampness and moisture can be used as a proxy of indoor microbial problem and subsequent exposure to microbial emissions [5]

The aim of this study was to determine the prevalence of moisture problems in the apartement buildings in Finland and possible association between mould or moisture problem homes and respiratory symptoms among a randomly selected population living in the apartement buildings.

2 Material and methods

2.1 Buildings and apartments

A random sample of 120 apartment buildings and two apartments from each building, that is 240 apartments in all, were randomly selected from the building registers of three cities. In each city equal sample size was selected from the buildings erected in the 1950's,1960's, 1970's and 1980's. Simple random sampling was used. These cities were Helsinki (population circa 500 000), Kuopio (population circa 83 000) and Oulu (population circa 100 000). A civil engineer, specially trained for this purpose, made a thorough walk through in the apartments and in the corridors, laundry, sauna and storage rooms that were in common use of the occupants. The roof, envelope and basement of the buildings were also examined. All the signs of moisture or moisture repair were recorded. Visual observations were confirmed with surface moisture recorders. In addition to this, the occupants and the house managers were interviewed for their observations and the damage and use history of the building. Moisture problems were graded into classes 0 to 5 according to their estimated severity:

- Class 0: No damages, or damages were repaired.
- Class 1: Only surface materials were wetted. Moisture has extracted by evaporating and drying.
- Class 2: Surfacing was detached, structures have to be dried and reglued or repainted.
- Class 3: Surface materials or structures, for example carpets or flagging have to be removed, base floor or roof opened and dried.
- Class 4: Whole elements of structures, such as supporting walls or basement floors, have to be removed.
- Class 5: Building is irreparable and purpose of use is unsuitable.

In those cases where there were more than one observation of moisture, the apartment was classified according to the most severe moisture damage.

2.2 Occupants of the apartments

Health questionnaires were sent to each individual living in these apartments. The occupants were divided into three categories according to their age. Each category had their own questionnaire. The categories were: children under seven years old (small children), children between 7 and 15 years old (school children) and people who were 16 or older (adults).

Questionnaires were sent before the civil engineer's examination. Questionnaires were turned in to the civil engineer, when he arrived to the apartment to make a walk through. All together 385 (3 18 adults, 27 schoolchildren and 40 little children) questionnaires were returned. Out of 3 18 questionnaire 188 were from separate apartments. That is at least one adult returned a questionnaire in 78% (82.5% in Kuopio, 85.0% in Oulu and 67.5% in Helsinki) of all the apartments.

2.3 Exposure

Exposure was defined in two different ways. Exposure to molds was defined according to occupants observations. If the occupant knew visible mold or had smelled the smell of mold or like, then the apartement was defined as moldy. Exposure to moisture was defined according to civil engineers observations.

2.4 Statistical methods

Prevalence of respiratory symptoms and infections between exposed and non-exposed groups were compared with multivariate logistic regression. Potential confounders for the health effects were included in the model. In these analysis age, gender, allergy and pets indoors were considered as confounders. Odds ratios were calculated as well as 95% confidence intervals (CI) for the point estimates of the exposure variables. SAS (Statistical Analysis System) software was used (SAS 6.09 for Alpha) [6].

3 Results

3.1 Buildings

In 60% of the apartements there were at least one sign of moisture present. This is a little less than the same figure of the single-family houses [7]. These figures include all the moisture problems, also those which had already been prepared. 12% of the moisture problems were graded into class 1, 45% into class 2 and 43% into class 3. There were no damages in classes four or five in these apartements. In all, 42% of the apartements were in need either a repair or more specific examination while the same figure in the single-family houses was 55%. Most moisture problems were in apartements built in 1950's and in 1970's and least in 1960's.

In this study rooms were divided into three categories: moist rooms (bathrooms, saunas, laundry rooms etc.), kitchen and other facilities (hall, living room, bedroom etc.). Most problems were in moist rooms. In 36% of the moist rooms that were studied a moisture problem was found (Figure 1).

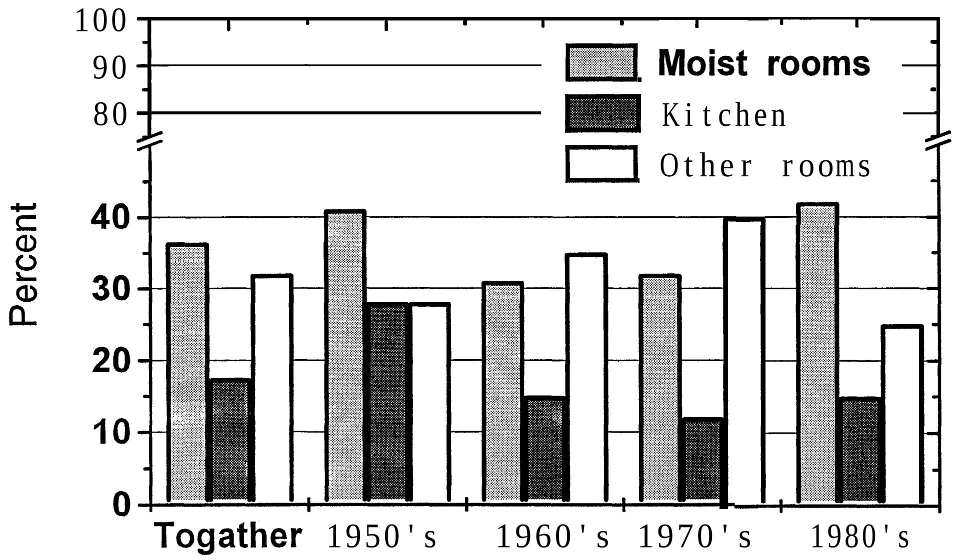

Figure 1. Moisture problems in percents in different facilities in different decades in apartement houses.

3.2 Exposure to molds

A total of 22 health outcomes were studied. For 19 health outcomes the proportion of those with the illness was higher in the exposed adults than respective non-exposed individuals (Table 1). Out of these 19 outcomes 9 symptoms were statistically significant.

Table 1. The proportions of the occupants with respiratory or non-respiratory illnesses and adjusted odds ratios for the association between mold at home and no mold at home in the past 12 months.

	Mold Absent	Mold Present		
Infection or symptom	l-l (%)	n (%)	OR	95% CI
Common cold	165 (64)	46 (84)**	2.34	1.03-5.33
Tonsillitis	10 (4)	5 (9)	2.49	0.76-8.15
Otitis	10 (4)	3 (5)	1.57	0.39-6.3 1
Sinusitis	34 (13)	21 (38)***	3.44	1.71-6.93
Bronchitis	23 (9)	12 (22)**	3.25	1.41-7.48
Cough without phlegm	46 (19)	17 (31)*	1.58	0.78-3.20
Cough with phlegm	56 (23)	26 (50)“““”	2.95	1.54-5.68
Nocturnal cough	22 (17)	13 (33)”	2.80	1.09-7.14
Nocturnal dyspnea	8 (13)	9 (45)**	18.36	2.74-122.9
Hoarseness	111 (52)	35 (67)	1.65	0.84-3.24
Sore throat	133 (63)	43 (80)*	1.96	0.92-4.16
Rhinitis	188 (84)	45 (87)	0.96	0.37-2.46
Nasal bleeding	52 (25)	17(32)	1.36	0.68-2.70
Impaired sense of smell	47 (23)	18 (35)	2.12	1.02-4.38
Eczema	45 (18)	13 (24)	1.31	0.63-2.76
Atopic eczema	15 (6)	2 (4)	0.60	0.12-2.92
Allergic eczema	27 (11)	7 (13)	0.88	0.32-2.41
Eye irritation	102 (42)	25 (48)	1.22	0.63-2.33
Nausea	70 (34)	23 (47)	1.38	0.70-2.72
Headache	169 (76)	49 (91)*	2.72	0.98-7.55
Fatigue	209 (90)	53 (98)	4.65	0.59-36.45
Difficulties in concentration	87 (42)	26 (51)	1.41	0.75-2.67

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Odds Ratios adjusted for smoking, age, gender, allergy, pets indoors and atopic predisposition. The number of occupants in exposed group was 55 and in non-exposed it was 260.

3.3 Exposure to moisture

A total of 22 health outcomes were studied. For 17 health outcomes the proportion of those with the illness was higher in the exposed adults than respective non-exposed individuals. Out of these 17 outcomes 8 symptoms were statistically significant (Table 2).

Table 2. The proportions of the occupants with respiratory or non-respiratory illnesses and adjusted odds ratios for the association between moisture at home and no moisture at home in the past 12 months.

	Moisture absent	Moisture present		
Infection or symptom	n (%)	n (%)	OR	95%CI
Common cold	109 (64)	102 (72)	1.18	0.67-2.06
Tonsillitis	5 (3)	10 (7)	3.00	0.87-10.35
Otitis	6 (4)	7 (5)	0.99	0.30-3.3 1
Sinusitis	19 (11)	36 (25)**	2.58	1.31-5.06
Bronchitis	17 (10)	18 (13)	1.61	0.74-3.52
Cough without phlegm	24 (15)	39 (28)**	2.00	1.08-3.69
Cough with phlegm	34 (21)	48 (36)*	1.94	1.11-3.40
Nocturnal cough	8 (10)	27 (31)**	5.78	2.14-15.61
Nocturnal dyspnea	4 (10)	13 (29)*	9.58	1.61-56.91
Hoarseness	68 (49)	78 (63)*	1.64	0.95-2.83
Sore throat	82 (59)	94 (75)**	1.73	0.97-3.09
Rhinitis	119 (80)	114 (90)*	1.48	0.68-3.22
Nasal bleeding	27 (20)	42 (34)**	2.32	1.25-4.32
Impaired sense of smell	29 (21)	36 (30)	2.06	1.07-3.96
Eczema	36 (22)	22 (16)	0.64	0.33-1.21
Atopic eczema	12 (7)	5 (4)	0.55	0.17-1.76
Allergic eczema	22 (14)	12 (9)	0.52	0.22-1.21
Eye irritation	63 (39)	64 (47)	1.49	0.88-2.5 1
Nausea	43 (32)	50 (42)	1.36	0.77-2.41
Headache	114 (77)	104 (82)	0.94	0.48-l .83
Fatigue	138 (90)	124 (95)	1.85	0.65-5.23
Difficulties in concentration	55 (41)	58 (48)	1.16	0.68-1.97

* p <0.05, ** p co.01

Odds Ratios adjusted for smoking, age, gender, allergy, pets indoors and atopic predisposition. The number of occupants in exposed group was 143 and in non-exposed it was 172.

4 Discussion

In 60% of apartements, signs of current or previous moisture damage could be observed. Part of the faults had been repaired, but 42% of the apartements were assessed to be in need of repair because of the moisture observations. The highest prevalence of moisture observations was found in the apartements built in 1950's and in 1970's. There were faults in both ceilings, walls, windows, roofs and pipings. In the facilities in common use, signs of moisture could be observed in nearly all the buildings (97%). Most faults were in the floor and wall structures of laundry rooms, saunas and storage rooms. Every second building had roof leakages or damage in the outer envelope. The most important causes for the faults originated from the time the building was erected, as mistakes in design or work; other causes were aging of materials and faults in the insulation.

Good maintenance of buildings is crucial in control, preventation and early detection of moisture problems. The health effects are caused by the emissions from microbial growth in building structures with excess moisture. Microbial growth in apartements should be considered a health risk and the moisture causing the growth should be repaired. Air outsets between the basement facilities and the apartements above them allows emissions to penetrate into the indoor breathing air of occupants.

References

1. Samet, J.M., Marbury M.C., Spengler J.D. (1987) *Health Effects and sources of indoor air pollution. Part* I. Am Rev Respir Dis 1987; 136: 1486- 1508
2. Koivisto, J. et al. *Moisture problems in Finnish apartment buildings - prevalence and repair costs*. Publications of the National Public Health Institute, KTL B9/1996, 86 pp + App (in finnish).
3. Dales, R.E., Burnett, R. and Zwanenburg, H. (1991) *Adverse health effects among adults exposed to home dampness and molds,* American Review of Respiratory Disease, 143, 505-509.
4. Jaakkola J.J.K., Jaakkola, N. and Ruotsalainen, R. (1993) *Home dampness and molds as determinants of respiratory symptoms and asthma in preschool children,* Journal of Exposure Analysis and Environmental Epidemiology, 3, 129-142.
5. Brunekreef B. (1992) *Associations between questionnaire reports of home dampness and childhood respiratory symptoms.* The Science of the Total Environment, 127, 79-89.
6. SAS Institute Inc., SAS/STAT@ *User's Guide*, Version 6, Fourth Edition, Volume 2, Cary, NC:SAS Institute Inc., 1989. 846 pp.
7. Partanen, P. Et al. (1995) *Moisture problems in single-family houses - prevalence and repair costs.* Publications of the National Public Health Institute, KTL B6/1995, 48 pp + App (in finnish).

DESIGN FOR HEALTH
Healthy Building Project

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Abstract
In an effort to come to grips with health problems, in particular the Sick Building Syndrome (SBS), related to many newly and rebuilt housing estates, the Environmental Administration has initiated a joint project, together with a builder - Stockholmshem. This **healthy building** project is part of a general allergy campaign in Stockholm. In conjunction with the project design of a new housing estate, Mandeln, consisting of three building blocks with 6-8 levels and 114 apartments, a **Health- and Enviornment Program** has been put forward. The program prioritizes questions of indoor climate for healthy buildings with particular emphasis upon moisture control, emissions from materials and constructions, ventilation, noise and energy balance. A series of quantitatively verifiable **performance standards** is presented, and IAQ measurements and questionaires will be carried out after construction in a reference apartment and in four other occupied apartments.
In the program an effort is made to relate standards for healthy buildings to certain elements and guidelines for resourceful and environmentally adapted buildings. For example certain environmental controls of materials, energy economizing and waste treatment.
The project has also highlighted the necessity to systematically choose environmentally adapted and healthy building materials based upon clearly defined health and environmental criteria. A discussion is now taking place to develope a transparent system of ***Environmental Criteria for Building materials*** for the city of Stockholm (SMB). It is hoped this will enable builders and others to make conscious environmental decisions when choosing building materials in newly and rebuilt building projects.

Key words: Building design, materials and construction, moisure control, guidelines for health and environment, quality control, housing estate

INTRODUCTION AND AIMS

Together with a builder -Stockholmshem - the Environmental Administration of Stockholm has initiated a **healthy building** project. The aims of the project are:

- Follow and take part in the planning, building and evaluation of re-built and newly built housings estates, where the construction, installations and building materials have been chosen with special care so as to obtain a good indoor environment for the tenants.
- Gain more knowledge and experience of how healthy buildings can be constructed in practise.
- Put forward “good examples”.
- Relate healthy buildings to the on-going process and discussion of resourceful and environmentally adapted buildings (sustainable buildings).

Quality criteria for healthy buildings will be developed on a joint basis within the framework of the project. These can vary depending upon the buildings location and requirements.

The building process is a complicated planned process with many different disciplines and parameters involved, indoor- and outdoor environment, quality control, time and economy. During the last few years there has been a shift in Sweden from governmental and local council steering to increased self control by builders. Experience from building projects during the 80:s and increasing enviromental consciousness are also important factors in the changing preconditions for the building process. It is imperative that the development of systems of quality control and enviromental aspects (e.g. IS0 9001, 14001, etc) are integrated into the building process at early stages and are followed through during the buildings use.

METHODS

To date we do not have any clear scientific models capable of explaining the multitude of effects and causes involved in health problems related to buildings, especially SBS. The author maintains, however, that these health problems can be prevented in modern housing estates by correct design, an integrated approach to quality control and enivironmental aspects including clear guidelines, and consideration of or direct involvement of tenants. For this to take place it is necessary for working project groups to discuss and put forward health and environmental issues, and for the project leader/builder responsible to see that the necessary competence and quality control procedures are present and applied throughout the whole building process.

In conjunction with the project design of a new housing estate, Mandeln in the city of Stockholm, a **Health- and Environment Program,** including a series of guidelines,

has been presented and discussed within the framework of the working project group. The program puts forward both qualitative and quantitative goals and prioritises questions of indoor climate for healthy buildings with particular emphasis upon moisture control, emissions from building material and constructions, ventilation, sound and energy balance. Questions related to resource effective and environmentally adapted - sustainable buildings - are also put forward. The program is a reference standard together with the builders present standards and environmental policy, The City of Stockholms Enviormental Program, the Cities planning documents and complementary quality program and Environmental Manuals.
Construction of the Mandeln estate will begin in October 1997. The author will follow the building project through all stages and an evaluation and report will be made later.

A program for IAQ measurements will be carried out, in a sample apartment without tenants and four other normal apartments. A questionaire put out to the tenants about one year after construction during the heating season will also be evaluated.

A system of criteria for choosing environmentally adapted building materials is also under discussion.

PRESENTATION OF THE HEALTH- AND ENVIRONMENT PROGRAM

The program is project specific for the Mandeln estate and will be modified and revised later for more general use. The program consists of general and specific aims and includes quantitative standards for the indoor environment. Only a general outline can be presented in this paper.

Building construction and materials

It is necessary to plan for low emissions and healthy building materials in the structure, surface layers, interior fittings and installations. Such a plan should include the following:

- The chemical declaration of building products including additives, from both health and environmental aspects. The builder should consult chemical expertis. The moisture- and pH levels the materials can withstand in the surrounding construction should also be considered, ($pH_{accept} < pH_{critical} - \Delta pH_{safety}$)
- A risk evaluation of which pollutants are likely to be emitted to the indoor air from the building products and constructions.
- Smoothing compounds should have low alkalinity and not contain Portland cement.
- Measurement of emissions (VOC) from certain building surfaces after construction, before tenants move in, using FLEC (The Field and Laboratory Emission Cell) in a comparatve manner.

A plan for moisture control and dimensioning for the main construction components should be made and include as a minimum:

- Moisture characteristics and effects of building materials and construction.
- Acceptable moisture conditions and levels set in relation to critical construction damp levels and safety factors - e g higher pH in concrete with higher water/cement ratio, glueing techniques, surface pore-structure etc ($RH_{accept} < RH_{critical} - \Delta RH_{safe}$). RH 85% is suggested for normal cement floor structures.
- Acceptable and standardized damp measurements, the measured values should be less than the guideline value, including consideration of maximum variation, before laying floor coverings.

Guidelines for environmental control of materials in the construction:

- Materials and constructions with long durability should be chosen, and which can easily be dismantled and re-used.
- Emphasis should be put upon resource effective materials and usage without environmentally dangerous or disturbing substances.
- Materials containing PVC should be avoided where possible.
- Wood from tropical forests should not be used.
- Copper should not be used on roofs, outer walls and pipes as far as possible. Zinc roofing should also be avoided.

Ventilation and indoor climate

Guidelines and specifications for thermal climate, indoor air quality:

- The building should be well insulated and airtight.
- Sources of increased temperature should be taken into account when designing the building, e.g. windows facing south, etc.
- Cold surfaces should be avoided, and there should be no leakages in the building envelope.
- Outdoor air is preferably taken from the northern side of the building where possible.
- Air flows should be determined in relation to maximium moisture levels and temperature in the building,
- Outdoor pollutants should determine the position of intake air vents.
- There should not be any accidental return of exhaust air.
- Good air exchange rates and cirulation so that intake air is distributed to where people are.
- There should be possiblities for re-distribution of intake air, especially to bedrooms during the night.
- Microbiological growth in ventilation ducts should be avoided, and good cleaning possibilities should exist.

- Dry constructions and materials with low emissions and neutral odour should prevail.
- Informative and easily understandable instructions to tenants - of how they can effect and keep clean the ventilation.

Guidelines and specifications for sound and light:

- Sound-transmission class B according to the newly established Swedish Building Standard (SS 025267). This is better than class C, the minimum level for modern Swedish houses, but not as good as class A.
- Structure-born sound should be reduced to a minimum with appropriate sound insulation materials and constructions.
- Impact sound-reduction is considered important, particularly for floor surface layers.
- Components between floor structure and walls are important feactures to consider when sound insulating.
- Reduction of low and high frequency sounds should be of special concern when sound-proofing.
- Low level pressure decreases in the ventilation give both low sound and better effect.
- Three-way or equivalent two-way windows reduce sound levels and at the same time reduce heating costs.
- Large windows give good daylight but can also be a source of over heating.
- Light colours are considered more appropriate.
- Glaced balconies and verandas should be easy to clean.

Guidelines for electrical installations and energy economizing

- A five wire system for electrical installations.
- Stray currents in water pipes and radiators should be avoided.
- Placing electrical applìences with magnetic fields close to buildings should be avoided.
- Energy effective solutions give better economy and reduce the load on the environment.
- The buildings energy balance is of prime importance as regards both energy costs and indoor climate.
- A calculation of the buildings energy balance should be carried out and comply with The City of Stockholms program for “Energy Effective and Healthy Buildings”.

Waste treatmant

Guidelines for waste treatment should include:

- Possibilities for sorting environmentally hazardous waste and fractions for which there is producer responsibility, preferably within the building.
- Cupboard space for sorting provided for all appartments.
- Sorting of building waste produced during production into appropriate fractions for re-use. Environmentally hazardous and dangerous waste sorted for correct treatment.
- Minimize material wasteage and use returnable packaging during construction.
- Materials and constructions chosen so that dismantling and re-usage is possible.

Building production

A plan of control for low construction damp should include the following:

- A building design which takes into consideration necessary drying-out procedures for different materials and constructions, especially concrete floorings.
- Onsite weather protection of materials, inspection and specified damp and moisture levels before use in the construction. Measurement of relative humidity and temperature.
- Early assembly of roofs and protection of windows and door openings as far as possible.
- Verified construction damp control. Highest values and measurement methods should be specified in building documents for contractors. Inbuilt monitors may be used.
- The building construction should be able to withstand the moisture it will be subjected to in its lifetime.
- A plan for low construction damp should not exclude moisture dimensionering.
- A clean building progam should be developed.

Control of ventilation during and after construction:

- All components should be protected from dust and moisture. Ducts, fans, sound-proofers, vents, etc should keep their protective coverings until assembled.
- The ventilation should not be started until the building has been thoroughly cleaned.
- The ventilation should be in operation and controlled before the first tenants move in.

Quality control

A series of concrete performance standards are put forward for, moisture and emissions from building materials and construction, thermal climate, indoor air quality, ventilation, sound climate and magnetic field. These standards are quantified in an appendix to the program. The levels are above normal minimum Swedish Building Standards, but below those considered necessary for houses totally adapted for tenants with allergies. It is considered that these standards are reasonable preconditions for newly built healthy buildings and should not increase overall building costs. At this level about 85% of the tenants should experience the indoor climate as accepable in a standard questionaire.

To ensure that these aims and levels are followed inspection plans will be carried out, primarily concerning the most critical points which can effect the indoor climate. Control measurements of relevant performance standards will be carried out, and a standard questionaire for indoor climate and health will be carried out about 1 year after completion or before guarantee inspection (after two years).

A series of concrete and verifiable Performance Standards are presented in an appendix to the program. Special attention will be payed to the measurement of initial moisture levels at different depths in several concrete floor structures and at different intervals in time, both before and after laying inner flooring covers. These measurements will be related to theoretically expected values at critical depth (0.20 of structure thickness).

A report evaluating the results from the building project will be made later. A follow-up report is expected to be presented at the next Healthy Building conference in Helsinki, 2000.

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References

1. Andersson K et al: TVOC and health in non-industrial indoor environments. Report from Nordic Scientific Consensus Meeting, Stoskholm 1996.
2. BELBAB: Production adapted information on construction damp. SBUF, 1995.
3. Bornehag C-G: Pattern analysis of indoor air. Report R23:1994, Swedish Building Research Council.
4. Environment manual: J&W Building & Engineering Works in co-operation with City Council of Örebro, uppdate 1997.
5. Fritsche M, Sjöberg A & Wengholt Johansson H: Chemical emissions from flooring systems. Report P-97:1 Chalmars University of Technology, Department of Building Materials.
6. Gustavsson H: Chemical emissions from building materials. Rapport 1990:25, Swedish National Testing and Research Institute.
7. Harderup E: Moisture control in buildings. Report R32:1993, Swedish Building Research Council.
8. Hult M, Jonsson J-A: Environmental and allergy adapted kindergarden, Umeå, planing phase. Raport R113:1989, Swedish Building Research Council.
9. Hult M, Jonson J-A: Environmental and allergy adapted kindergarden, Umeå, building phase. Rapport R35:1991, Swedish Building research Council.
10. Hult M, Persson R: Allergy adapted housing - a general base for planing. Report R1:1991, Swedish Building Research Council.
11. IS0 9000: Correct quality in the building process - a guide.
12. Jonsson J-A, Hult M: Environmental and allergy adapted kindergarden in Umeå, evaluation. Report R25:1993, Swedish Building Research Council.
13. Moisture group, Lunds University of Technology: Moisture control in buildings, reports T10:1993, T17:1993, T27:1993, T15:1994, T10:1995, T12:1995 & T13:1995, Swedish Building Research Council.
14. Nevander L E, Elmarsson B: Moisture Handbook. Swedish Building Service 1994
15. NKB: Indoor Climate and Quality, NKB-publication no. 95:12
16. Nordquisst B: Good examples of healthy buildings. Report TABK-95/7032, LTH, Department of Building Construction.
17. SBUF: Drying-out of initial moisture in concrete - an easy guide. SBUF inform no. 95:12.
18. Sundell J & Kjellman M: The Air we Breath Indoors, 1995. Swedish National Insiitute of Public Health
19. Valbjörn 0, et al: Indoor Climate Problems. Investigation and remedy. SBI-Raport 246, The Danish Building Rearch Institute. (See also Nordtest Report 204, 1993 for English version).
20. Wengholt Jonsson H: Chemical emissions from flooring-structures. Report P-95:4, Chalmars University of Technology, Department of Building Materials.

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Indoor environment and health

PARAMETER	LEVEL	COMMENTS
Thermal climate:		
Room temperature	22 ± 2° C	Winter at DOT (3*)
Air speed,occupied zone	0,15 m/s	Normal vent. (BBR) (4*)
	0,20 m/s	Increased ventilation
Floor temperature	18-24° C	Lower air temp. acceptable at higher floor temps.
	20° c	Lowest level in bathroom
Relative Humidity	<75% during summer	Preferably >25% wintertime
Air quality:		
Cooking fumes	Not between apartments	Poss, to increase extract air
Nitrogen oxides	0,05 mg/m^3	Mean value 24h
Formaldehyde	<0,05 mg/m^3	Mean value 8h
Particals in intake air	<20 000 parts./m^3(1-10µm)	After filter
Airbourne particals	60 µm/m^3 (<10µm)	After cleaning&before use
Radon gas level	200 Bq/m^3	(BBR)
Gamma radiation	0,5 µSv/hour	(BBR)
VOC in room air	No unnormal levels of irritants &/or indicaters	Approx 1 year after comple-tion
Ventilation:		(Exhaust system)
Volume exchange-rate	0,6 - 1,0 ACH	Extract volume rate
Carbon dioxide in bedroom	1000 ppm	Winter, higher level accepted
(redistribution to b-rooms)	(10 l/s - for 2 persons)	(BBR, etc)
Air-exchange efficiency	45%	Extra supply-air device
Flexibility:		
Total flow increase	0-50%	In the whole housing block
Redistribution of flow	Partly	Within apartments
Demand controlled vent.	±50%	For whole apartment
Operation & Maintenance:		
Cleaning accessibility	In neutral spaces and some apartments	
Accessibility/supervision	Partly free from the structure	
Periodic maintenance	According to a central plan	
Operating economy:		
Net recovery efficiency	60%	Energy in ventilation air
Specific fan power (SFP)	0,8 kW/m^3/s	Extract ventilation
Degree of insulation	1,5° c	Max temp. decrease vent.air
Sound:	Sound-transmission class B (minimum level for good sound environ-ment, better than normal standard class C) (5*)	
Sound insulation	Including reduction of low frequency noise (6*)	
Outdoor noise	Noise levels in SNVs guidelines are aimed at (7*)	
Electro-magnetic fields:	**(8*)**	
Magnetic field	<0,2 µT	Permanent installations only

(3*) Design Outdoor Temperature
(4*) National Board of Housing, Building & Planing Building Regulations, minimum levels for Swedish houses
(5*) Swedish Standard SS025267, 4 sound-transmission classes are defined A,B,C and D where A is very good sound conditions
(6*) See National Board of Health and Welfares, Guidelines and Recommendations for Indoor Noise &High Sound Levels 1996:7
(7*) The National Environmental Protection Boards recommendations for external noise-levels
(8*) Swedish Building Council, 1992, T:134 recommended values for power-freqnency electrical fields & magnetic fields

Classification of Indoor Climate, Construction, and Finishing Materials

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Abstract

Good indoor climate is one of the main goals of building design and construction. Studies all over the word have shown that this goal is far too seldom obtained as research results are not applied to the practice.

To overcome this problem of information transfer between research and practice, a design guide for good indoor climate was prepared in Finland. It was done with co-operation between the Finnish Association of Construction Clients, the Finnish Association of Architects, the Finnish Association of Consulting Engineers, and the Finnish Society of Indoor Air Quality and Climate.

The documents consists of three parts: 1) Classification of Indoor Climate, 2) Classification of Construction Cleanliness, and 3) Classification of Finishing Materials. Because requirements for all buildings are not always the same, all the parts present the criteria and requirements on two or three quality levels. The lowest category corresponds to the present building practice set by official building codes. Higher categories present significant improvement in the design and construction for better indoor climate. The construction client selects the categories with the design team at an early stage of a construction project. The classification can be referred to in the building specifications. It can be used in new constructions and in evaluation of old buildings, as well as in renovations.

The Classification of Indoor Climate includes target values for indoor air quality and climate. It also gives the most important design values for heating, ventilation and air-conditioning equipment. The Classification of Construction Cleanliness deals mainly with the principles and procedures to be followed at various stages of construction works. The Classification of Finishing Materials contains limit values for chemical emissions of building materials. In addition, it presents the maximum surface area of materials allowed in a space to obtain the requirements of the selected category of indoor climate.

The Classification is intended to be used during the design and contracting phases of construction works and mechanical systems for buildings. It also gives guidelines to manufacturers of equipment and materials to produce better building products in respect of good indoor climate. The Classification can be used both for new constructions and renovations, and also during the evaluation of buildings.

Keywords: air quality, cleanliness, design values, healthy buildings, indoor climate, material emissions, ventilation

Introduction

Indoor climate has become more important for health and comfort during recent years. As people stay indoors approximately 90% of the time, the quality of indoor air for the health is even more important than outdoor air. Good indoor climate reduces illness and the symptoms of sick building syndrome. It also influences comfort and working efficiency. The costs caused by poor indoor climate in the Finnish building stock has been estimated to be 18 billion Finnish marks per year (app. 3 billion ECU), corresponding to the costs of energy consumption of buildings.

Good indoor climate is one of the most important factors in assessing the quality of a building. Research and practice have, unfortunately, shown that good indoor climate is not always achieved. Indoor climate is influenced simultaneously by several factors, such as heating, ventilation and air conditioning, construction methods and materials, operation, maintenance and use of buildings. The Classification of Indoor Climate, Construction, and Finishing Materials /1/ presents guidelines considering all these factors. It has three parts and is intended to be used in design and construction of buildings and their mechanical systems. It also encourages manufacturers of equipment and materials to produce low-emitting building products.

The Classification of Indoor Climate, Construction, and Finishing Materials was developed by Finnish Society of Indoor Air Quality and Climate (FiSIAQ) based on Finnish and international research results. The work was sponsored by the Finnish Ministry of the Environment.

The Finnish classification

The final quality of indoor climate is influenced simultaneously by heating, ventilating and air-conditioning systems and equipment, by the performance of the construction and materials, and by the operation and maintenance of the building. To achieve a good indoor climate, all the guidelines presented in the Classification need to be taken into account throughout all the phases of design, construction and operation. The Classification has three parts: Part 1, Indoor climate; Part 2, Cleanliness of construction; Part 3, Finishing materials and it is intended to be used during the design and contracting of construction works and mechanical systems for buildings, and in the manufacturing of equipment and materials to build healthier and more comfortable buildings. The Classification can be applied to new buildings and for evaluation of all buildings and, when applicable, also during renovation. The Classification gives target and design values for indoor climate and supports the work of clients, designers, equipment manufacturers, contractors and operation personnel. The Classification can be referred to when writing up specifications of construction and mechanical systems. It can be used even as an attachment to such specifications. The Classification does not overrule official building codes or interpretations of them.

When the ultimate goal is good indoor climate, the best category of each part of the Classification has to be selected. The low category of one part cannot be totally compensated by a high category of another part. Thus, for example, the high emissions of building materials are difficult to be compensated by increasing the ventilation.

Selection of categories

The Classifications of Indoor Climate and Finishing Materials have three categories, and the Classification of Construction Cleanliness two categories. Indoor Climate category S 1, Construction Cleanliness category Pl, and Material category Ml correspond to the best quality. Categories S3, P2 and M3 are in line with the official quality set by building codes and regulations.

The categories for indoor climate, construction cleanliness, and finishing materials shall be selected at an early stage of a construction project. The client selects the categories with the design team. With the help of the Classification of Indoor Climate, the target values for the indoor climate are specified. After this, the category of Construction Cleanliness is selected in accordance with the Classification of Construction Cleanliness. The Classification of Finishing Materials is used when selecting building materials. If necessary, the target values and requirements can be selected from different categories. However, when the ultimate goal is good indoor climate, the best category for each part of the Classification shall be selected. The low category of one part cannot be totally compensated by use of a high category for another part. Thus, for example, the high emissions of building materials are difficult to be compensated by increasing ventilation. So far, it has not been possible to take into account material emissions when selecting airflows for ventilation because the finishing materials have been selected at a late stage of the construction process.

The classification of indoor climate (Part 1)

The Classification of Indoor Climate deals with common work and living spaces (office and public buildings, schools, day-care centers, dwellings, and other buildings of similar type). The Classification has three categories: Categories I, II and III. Category I is the best meaning higher satisfaction with indoor climate and lower level of complaints. For example in respect of room temperature, Category I corresponds to 90% of satisfaction. Category III corresponds to the requirements set by building codes.

Target values

The target values of indoor climate factors (Table 1) are used to specify the target level of indoor climate at an early stage of a building project. The target values can also be used for checking the indoor climate and compliance with the requirements. The target values apply to the zone of occupancy of a room which usually extends from the floor surface up to 1.8 meters from it. It begins 0.6 meters from the walls.

The concentrations of indoor air pollutants presented in Table 1 will not be exceeded in general if the ventilation rates are as high as specified in the tables, and if there are no specific pollutant sources in the room. Thus, the measurement of indoor air pollutants is not generally required.

The Classification does not give limit values for concentration of microbes because the building may have mold damages even if the room air does not contain high concentration of bioaerosoles. The concentration of bioaerosoles may vary strongly depending on time, location, conditions and species of microbes.

Design values

The design values presented in Table 2 should be used specifically in dimensioning of heating and air conditioning equipment. The designer also has to define the conditions where the building conforms to the design values including loads and operation of the room (number of occupants, lighting load, equipment load, etc.) and external loads of a room. Design weather conditions are given in the document, too.

Verification of limit values

The design and limit values of a building should be checked when the building is in operation, in winter when the outdoor temperature is below -5 °C, and in summer when the outdoor temperature is above 20 °C and the weather is clear. The compliance of design and target values in other than design conditions have to be checked with calculations taking into consideration also the capacity of heating and cooling equipment. Design and limit values of indoor climate have to be measured with the instruments which a have calibration certificate.

Classification of cleanliness of construction (Part 2)

The Classification of Cleanliness of Construction gives the requirements for construction and air handling equipment, their installation and use. The extend and level of requirements depend on the category which is aimed at. The Classification has two stages: Category 1 corresponds to the best quality and category 2 to the level of present construction practice. Good indoor air quality provides co-operation between all parties involved in the construction project and the fulfillment of all the requirements given. The requirements are given mainly to contractors but also to designers, equipment manufacturers, and users of the building.

The requirements in category 1 include, for example, the following:

Air handling system and equipment

Ductwork. The ductwork has to be cleaned after the manufacturing so that the interior surface of the ducts does not contain oil residues or other harmful substances. The ductwork should be protected from dirt and rain during the storage at the factory and during transportation, as well as at the construction site and in the temporary storage at the installation site. Open ends of ductwork have to be capped during the breaks of installation. The ductwork has to be built so that it can be easily cleaned without damaging the equipment. The ductwork has to be cleaned before the operational test of the air handling systems.

The use of air conditioning equipment during the construction work. The final air conditioning equipment shall not be used for heating, ventilating or air conditioning of the building during the construction process. The operation of air conditioning equipment should be limited only to perform the balancing and measurements after the operational tests.

Air handling units. The supply air of the air handling units has to be cleaned with a filter with dust removal efficiency better than EU 7 (F7). The supply air must not bypass the filter media through the holes or openings between the frames and air handling unit.

Heat recovery from the exhaust air. The pressure of supply and exhaust air has to be controlled so that exhaust air cannot flow through possible leakages in the heat recovery unit to the supply air. Regenerative heat recovery equipment (heat wheel etc.) can be used only when the exhaust air does not contain tobacco smoke or other harmful contaminants.

Use of return air. Return air should not be used in air handling units with the exception of air handling units which only serve one dwelling.

The construction of air handling units. The interior surfaces of air handling units have to be easy to clean. The air handling units have to be air tight so that unclean air cannot enter to the supply air flow.

Cleaning of the ducts. Supply air ductwork has to be inspected with a maximum interval of five years. If the duct contains dust (dust accumulates when sweeping the surface), the ductwork has to be cleaned.

Replacement of filters. The filters of air handling units have to be replaced according to final pressure drop defined by the designer or, at latest, when 50 % of the area of the back side of the filter media has changed its color due to dust.

Structural and architectural work

The section dealing with construction work presents the requirements in the following areas: 1) Separation of the rooms with different categories; 2) Transportation of materials and accessories; 3) Storage of building materials on the construction site; 4) Protection of building materials during the installation and actual construction work; 5) Labeling and protection of cleaner areas during the construction; 6) Cleaning of the spaces during the construction; 7) The final cleaning of the spaces.

Classification of finishing materials (Part 3)

The purpose of the Classification of Finishing Materials is to present requirements for the materials used in common living and work spaces to achieve good indoor air quality. The goal is also to enhance the use and development of low-emitting materials. However, the use of low-emitting materials does not guarantee good room air quality. Ventilation has at the same time to be adequate and the materials should be used according to the manufacturers' specifications. For example, very few materials can stand for excessive moisture. Materials should also be easy to clean.

The Classification of Finishing Materials has three categories, category A being the best and category C containing materials with highest emission rates. Because total emission and concentration in room air depend on the amount of used materials, the Classification gives guidelines for the use of various materials. When the best indoor air category I is selected, the use of higher-emitting materials (categories B and C) has to be limited.

Requirements for finishing materials

Category A: Category A is designated for natural materials, such as stone and glass, which are known to be safe in respect of emissions, and for materials which fulfil1 the following requirements: 1) The emission of total volatile organic compounds (TVOC) is below 0.2 mg/m^2h; 2) The emission of formaldehyde is below 0.05 mg/m^2h; 3) The emission of ammonia is below 0.03 mg/m^2h; 4) The emission of the carcinogenic compounds (due to IARC) is below 0.005 mg/m^2h; 5) Material is not odorous (dissatisfaction with the odor is below 15%).

Category B: 1) The emission of total volatile organic compounds (TVOC) is below 0.4 mg/m^2h; 2) The emission of formaldehyde is below 0.125 mg/m^2h; 3) The emission of ammonia is below 0.06 mg/m^2h; 4) The emission of the carcinogenic compounds (due to

IARC) is below 0.005 mg/m²h; 5) Material is not strongly odorous (dissatisfaction with the odor is below 30%).

Category C: Category C is for the materials which do not have emission data or the emission data exceed the values specified for materials of category B.

Classified materials must have a product specification which should present emission data and the possible limitations for the use of material and the requirements for environmental conditions when the material is applied. The producer should also have an acceptable quality control system.

The emissions of the materials shall not be greater when the material is in actual use than in the measurement test conditions. For example, the materials which are intended to be used in wet conditions have to stand for high moisture concentration without damage or increase in emissions.

The use of finishing materials

The finishing materials should be selected mainly from category A for the indoor climate category I. The finishing materials belonging to category B must not cover more than 20% of the interior surfaces of a room or not more than 1 m^2 per floor area. The use of the materials belonging to category C should be limited to minimum.

The finishing materials used in indoor climate category II should belong mainly to categories A and B. Materials belonging to category C should not cover more than 20% of the interior surfaces of a room or not more than 1 m^2 per floor area.

Measurement methods

The measurement of emissions should be performed when the material is in the actual final form intended for its use. Material emissions shall be measured according to the methods specified in Nordtest or ECA guidelines /4, 5/. The sampling and analyses of chemicals have to be made according to commonly accepted methods. Emissions of materials shall be measured after four weeks from the date of the production or the date when the material is unwrapped from the air tight packing. The samples shall be stored for four weeks before the test in a climate chamber. The time of four weeks will be calculated for paints, levelling agents, adhesives, sealants, etc., from the date of application on the surface. The procedures used in the sample selection and preparation follow the principles outlined in the project "European Data Base on Indoor Air Pollution Sources" /3/.

Experience in practice

The Classification of Indoor Climate, Construction, and Finishing Materials has been adopted for several construction projects. Construction clients and designers have used it as a tool in setting target values for indoor climate and in achieving the goals during the construction. In a year, 2,000 copies of the Classification have been distributed to various parties involved in construction. The Classification has also been translated into English.

The classification has been used in several building projects.

The Classification has been received positively also by the construction industry and by the manufacturers of building materials.

The first part of the Classification, which deals with the target values of indoor climate, have been used widely by designers in various building projects. The target values have also been used as a reference values in the building investigations.

The second part dealing with construction cleanliness has maybe faced the strongest opposition from contractors, the main reason being the unawareness of the nature of the indoor climate problems. However, after the major designers having adopted the principles presented in the Classification in their design it looks like the document is gradually changing the construction practice. It is, for example, more and more common that designers specify that the ducts have to be washed after the manufacturing process and handled on the construction site with capped ends. The largest project in Finland where the classification of the construction cleanliness has been used is the NOKIA headquarters building where 25 km of cleaned ducts have been installed, and the classification followed in other aspects, too. The classification has also been used succesfully in the design and construction of an appartment building for people suffering respiratory diseases /6/.

The third part of the classification, which deals with the material emissions have been used in practice since June 1996. The driving force in the classification for material emissions has been the Finnish Building Information Institute, an organization owned by Finnish architects, which has founded a committee to classify the materials. It makes decisions on the categories of the finishing materials. In the committee, there are representatives of researchers, various construction parties, and material manufacturers. The Finnish Building Information Institute publishes data on classified products. Thus the material manufacturers get free advertisement through the Institute. The committee's decision on emission classes are based on the test data from the certified laboratories. By the end 1997 about one hundred and fifty materials have been granted with the class Ml label. The material manufacturers have started to use the classification certificate and label also in their advertisements, not only for professionals but also for public.

References

1. Finnish Society of Indoor Air Quality and Climate FiSIAQ, Finnish Association of Construction Clients RAKLI, Finnish Association of Architects SAFA, Finnish Association of Consulting Firms SKOL. ***Classification of indoor climate, construction, and finishing materials.*** FiSIAQ Publication 5E. Espoo 1995.

2. CEN prEN1752. ***Ventilation for Buildings:*** Design Criteria for the Indoor Environment. 1996.

3. ***European Data Base on Indoor Air Pollution Sources in Buildings.*** Contract. JOU2-CT93-0343 for the European Commission in the fame work of the JOULE II - Programme.

4. Nordtest. ***Building materials: emission of volatile compounds, chamber method.*** Nordtest method, NT BUILD 358. Nordtest, Espoo 1990.

5. ECA. ***Guideline for the*** *characterization* ***of volatile organic compounds emitted*** *from* ***indoor materials and products using small test chambers.*** EUR 13593 EN. European Collaborative Action (ECA), 1991.

6. Tuomainen M., Pasanen A-L, Kalliokoski P, ***Practical aspects of design and construction of a block of*** *flats* ***with good indoor air climate.*** Proceedings of Healthy Buildings '97, Vo13 p. 357.

Table 1. Target values of indoor climate.

Factor	unit	S1	s2	s3
			Category	
Room temperature, winter	°C	21-22	21-23	20-24
Room temperature, summer	°C	22-25	22-27	22-27 (35) *
Floor temperature	°C	19-29	19-29	17-31
Vertical temperature difference	°C	<2	<3	<4
Air velocity, winter 21°C	m/s	<0.10	<0.15	<0.15
Air velocity, summer 24°C	m/s	<0.15	<0.20	<0.25
27°C	m/s	<0.20	<0.25	<0.30
Relative humidity of air, winter	%	25-45		
Relative humidity of air, summer	%	30-60		
Noise level of heating and air-conditioning equipment	dB(A)			
offices		<30	<35	<35
living and bedrooms		<25	<25	<28
Air change rate (residence)	l/h	>0.8	>0.6	>0.4
Odor intensity	desipol	<2	<4	<5,5
Total volatile organic compounds	mg/m^3	<0.2	<0.3	<0.6
Formaldehyde (H_2CO)	mg/m^3	<0.03	<0.05	<0.15
Ammonia (NH_3)	mg/m^3	<0.02	<0.03	<0.05
Carbon dioxide (CO_2)	ppm	<1000	<1250	<1500
	mg/m^3	<1800	<2250	<2700
Carbon monoxide (CO)	mg/m^3	<2	<5	<8
Ozone (O_3)	mg/m^3	<0.05	<0.07	<0.10
Total suspended particles	mg/m^3	<0.06	<0.06	<0.06
Radon (Rn)	Bq/m^3	<200	<200	<200

Design values of outdoor airflows for air quality	S1 L/s,p	S1 L/sm^2	s2 L/s,p	s2 L/sm^2	s3 L/s,p	s3 L/sm^2
offices	16	2	12	1.5	8	1
conference rooms	12	8	9	6	6	4
classrooms	12	6	9	4.5	6	3
lecture halls	12	12	9	9	6	6
day-care centers	10	4	7.5	3	5	2
living and bedrooms	8	1	6	0.7	5	0.5

* room temperature shall not exceed +35 °C; room temperature shah not be above +27°C when outdoor temperature is below +15 °C

'-' stands for no specific requirements are set

Guidelines for indoor climate investigations in residential buildings

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Abstract
Healthy and comfortable indoor climate is a basic requirement for all buildings. Complaints by the occupants and observed defects and malfunctions of the building and its mechanical equipment are reasons for investigating and renovating the building. The goal of the research was to develop a method for investigating indoor climate in residential buildings. Guidelines for the investigation were made for both houses and apartment buildings. As the outcome, the investigations produce data for the renovation of indoor climate in buildings. The indoor climate investigations in residential buildings proceed step by step, and the levels can be applied according to the buildings investigated. The guidelines consist of the measures and methods including measurement equipment needed in the investigations. The indoor climate investigations include the following steps:

- assessing of indoor climate problems by interviewing occupants and maintenance personel of the building
- examining of the performance, condition and balance of ventilation system and comparing them to the design specification
- examining of air flows, pressure differences and air tightness of the building
- examining of the performance, condition and balance of heating system
- examining of the condition of constructions, e.g. water damages and the effect of ventilation on them
- assessing of thermal conditions, humidity and pollutants
- measuring of indoor climate parameters (temperature, humidity, pollutants of indoor air, etc)

Keywords: indoor climate, dwellings, investigation method, diagnostics

Introduction

According to research results /1/, indoor climate in buildings varies a lot. For example, the difference of air flows can be tenfold between buildings. The defects of ventilation equipment, and moisture and mould damages are prevalent. The cost caused by poor indoor climate in the Finnish residential buildings has been estimated to be about four billion Finnish mark per year, being twice as much as the cost of energy consumption for ventilation. The consequences of poor indoor climate appear as various symptoms and illnesses, and discomfort.

Investigations /2/ concerning mechanical exhaust ventilation in block of flats built in the 1960's and the 1970' showed that when all the windows are closed, only one fifth of the exhaust air flows from kitchen or bathroom met the requirements of the National Building Code of Finland.

There are 2.4 million dwellings in Finland, one million in detached houses and one million in blocks of flats. The average age of the whole stock of dwellings is 31 years. The 300 000 dwellings in terraced houses are typically fairly new, more than 60 per cent of the terrace houses has been built after 1980. Mechanical exhaust is the most common ventilation systems in Finnish dwellings.

Table 1. Ventilation systems in Finnish dwellings.

Year of construction	**Block of flats**	**Detached houses**
before 1960	natural ventilation	natural ventilation
1960-1970	mechanical exhaust	natural ventilation
1970-1980	mechanical exhaust	mechanical exhaust
1980-1990	mechanical exhaust	mechanical exhaust mechanical supply and exhaust
1990-	mechanical exhaust mechanical supply and exhaust	mechanical supply and exhaust

Blocks of flats do have central heating system based on district heating. About 40 % of detached houses are heated using electricity and with oil heating 30 %.

The aim of the project was to develop a method for indoor climate investigations and to formulate guidelines for how to investigate indoor climate in residential buildings. The investigation of the building will produce basic information on indoor climate. The reasons to investigate indoor climate can be, for example, poor performance of the building or of the mechanical equipment, or symptoms and complaints by the occupants. The main goal is to prevent indoor air quality problems by increasing regular maintenance and inspection work in dwellings. The project was a part of Building Renovation Program (REMONTTI Programme) /3/ financed by the Finnish Ministry of the Environment.

Contents of guidelines

The guidelines present a method to investigate the problems of indoor climate in dwellings in phases. The guidelines include also lists of typical indoor climate problems and their causes, table 2. Measurements of parameters that are often difficult to interpret will be made only after preliminary walk-through. The starting point is to examine the performance of the mechanical equipment and the defects in them. The necessary and urgent repairs for the buildings, for example technical breakdowns and the need for basic balancing of ventilation and heating system, will be presented as a result of the indoor climate investigation. In the report, some measures to improve the indoor climate in buildings are presented.

The investigations proceed, deepen and expand in phases. Typical indoor climate investigations in dwellings as well as the methods of measurement and interpretations of the results are described. A previous condition assessment of the building can be the starting point for the indoor climate investigation. It is beneficial and also cost effective if other investigations can be performed simultaneously in the same building, especially the investigation of mould problems. Descriptions of typical malfunction and defects of ventilation systems with a recommendation for improvement are a part of the guidelines for the indoor climate investigation.

Structure of indoor climate investigation

The structure of the indoor climate investigations is presented in Figure 1.

Acquisition of basic information

In the first phase, the necessary background data of the building are collected. e.g. the construction and IIVAC-systems, the operating time and zones of the ventilation system. The data are used to design measurements. A survey of previous evaluation assessments and investigations as well as other reports, measures and renovation will be made. Furthermore, the design and service documents are acquired in advance.

Overview of the recognized problems in dwellings is the starting point of the investigation: the complaints by the occupants and symptoms associated with indoor climate, and the defects of the building and of its mechanical equipment. The aim is also to try to find out the extent and seriousness of the problems.

The basic data are gathered with the help of the manager and janitor of the building. For a residential building, these data can be collected already at the ordering stage of the investigation. The model of the order is included in the guidelines.

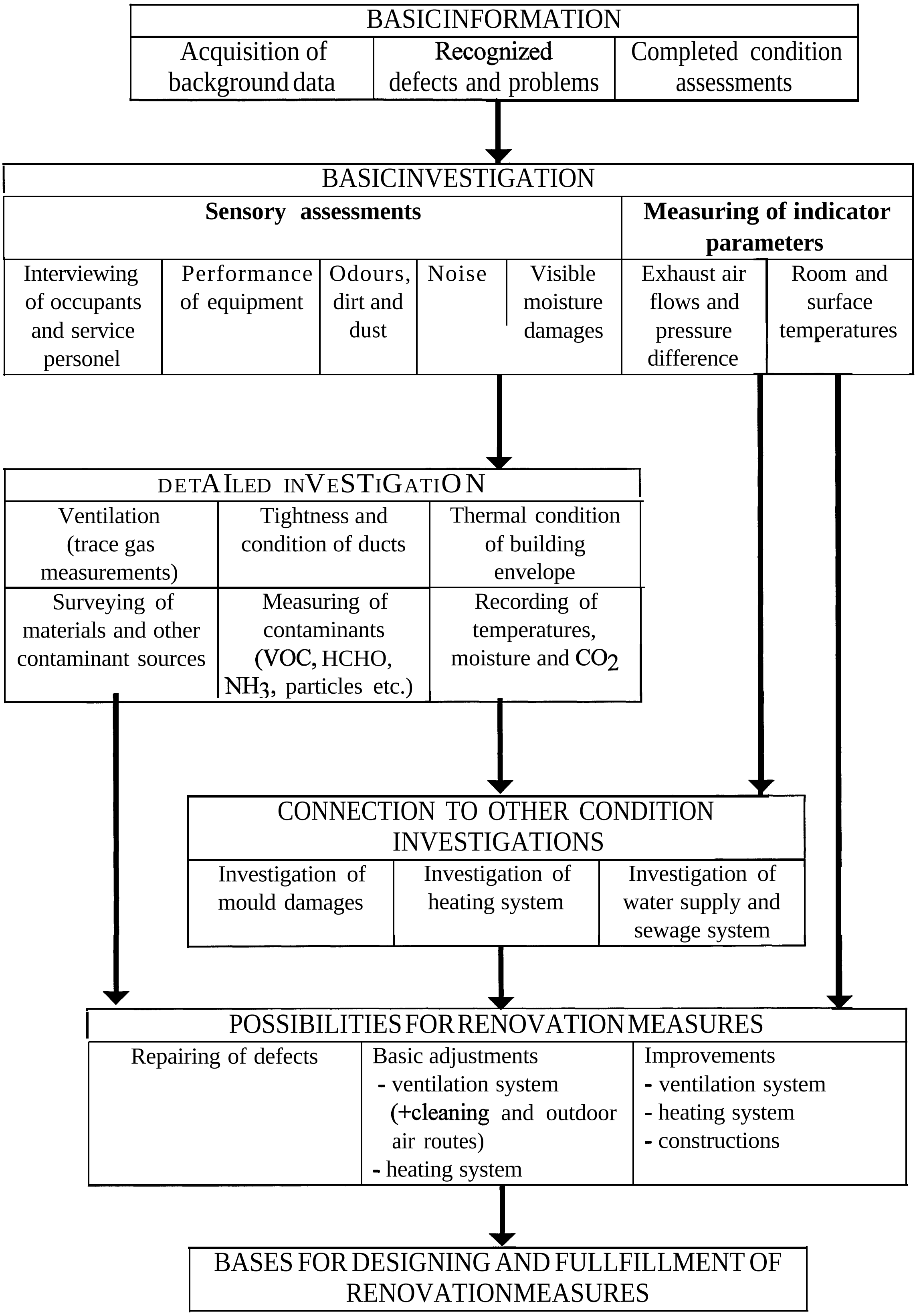

Figure 1. The structure of the indoor climate investigations.

Sensory assessment

When specifying the quality and extent of the problems, the key persons of the building are interviewed. Depending on the size and ownership of the building, the key person include the chair of the building board or a representative of the tenants, the manager of the building, and the janitor. At the same time, inadequate data are completed. The need for a questionnaire for the occupants is estimated. For example, in large building complexes with the questionnaire for the occupants, poor operation of ventilation and heating system can be limited to certain zones.

This phase is based on a walk-through survey. The building is examined from outside and by walking through the common spaces and the roof. The functioning and operating times of the ventilation equipment are checked in the machine rooms of air handling units and the main distribution board; operation of the fans and timers are checked at each speed. The set values, control curves and the functioning of timers of the heating system are checked in the heat distribution room.

All apartments in the building must be investigated. In the apartments, the indoor air quality is assessed on sensory basis. In the assessment, the stuffiness of the room air is evaluated and possible odours specified and their sources located. The condition and operation of the ventilation system in the dwellings are assessed. The cleanliness and the position of the supply air inlets, exhaust air outlets, and the kitchen range hood as well as transfer air routes are examined; special attention is paid to the flow routes of outdoor air. The condition and performance of heating equipment are examined (e.g the type of radiator valves). Visible moisture damages are recorded with the help of the check list of mould problem investigations. Based on the results, the need for special mould investigation is assessed.

Measuring of indicator parameters

Very seldom a single contaminant in the air is the reason for the problems. This is why there is usually no need to measure the concentration of single substances in the beginning of the investigation unless there is a good reason to suspect that some material emit that a specific chemical. On the other hand, measuring or assessing of some indoor climate parameters as an indicator is often very useful. The occurrence of a factor and order of its magnitude may describe the quality of the building or a special kind of problem.

Some apartments are selected by taking into account the zones of the ventilation and the heating system (in apartment buildings for example at different staircases both on the top and the first floor). The following factors are suitable to be taken as the base of first hand conclusions; exhaust air flows, pressure differences, air temperature, surface temperatures, carbon dioxide concentration, and the noise caused by ventilation and heating system. It is often plausible to do the evaluation of indicator parameters simultaneously with sensory assessments. Air flows in all dwellings having natural exhaust ventilation or their own ventilation unit must be measured. The condition, cleanliness and adjustment of ventilation equipment are worked out more precisely (fans, air intake, filters, heat recovery, ductwork).

Measured values are compared with values in the National Building Codes or in the Classification of Indoor Climate /4/. Air temperature is compared during the heating period to the value of 21,5 °C. The reason for an air temperature value deviating more than +/- 1,5 °C has to be found out. Exhaust air flows are compared to design or guideline values. When this deviation is more than +/- 20%, this part of ductwork needs to be adjusted. When the exhaust air flows are clearly lower than their target values, the need for outdoor air routes are assessed by measuring the exhaust air flows with the window open and closed. The sufficiency of the fan power is also assessed. With the trace smoke, outdoor air routes and internal air flows are studied, and draughty locations and air leakage in the building envelops are searched for. The pressure difference between room air and outdoor air and staircases are checked. The moisture loads of the apartment are evaluated (the use and type of humidifiers, the amount of laundry and the way of drying it, and the frequency of use of shower and sauna). Also the sources of contaminants are recorded (e.g. pets and amount of dust accumulating surfaces).

In the common spaces, the same indicator parameters as in the apartments are measured (sauna department, laundry rooms, drying rooms, club rooms, store rooms, garbage rooms, survival shelters, and possible commercial spaces).

Detailed investigations

The thermal insulation of the building envelop is assessed when it is suspected that the capacity of the radiators is inadequate. Measuring of air leakage in dwellings is needed when designing the basic improvement of ventilation system. The air tightness of the external envelope in buildings with natural or mechanical exhaust ventilation system has been a typical constructional deficiency impairing indoor air quality in dwellings. In a building with tight envelope, the air change rates are almost systematically lower than the target values. Measuring the operative temperature is necessary in old dwellings and in those with floor or ceiling heating. A long-term recording of room temperature may be needed for example when night setback is used. The CO, concentration in the buildings is measured if the CO, production before the measurement is representative. By the long-term recording of CO, concentration, the adequacy of air change in bedrooms can be evaluated.

In a building with natural ventilation, or with mechanical exhaust with , the air tightness of the ducts is measured when needed. With trace gas measurements, contaminant transfer between apartments can be investigated. Also, the actual air change rate in a dwelling can be measured exactly with trace gas techniques.

A survey of building materials is made when searching for a reason for an exceptional odour or high contaminant concentrations, for example dust, carbon monoxide, ammonia, formaldehyde and volatile organic compounds. The need for measuring radon is estimated on the basis of soil, type of foundation and ventilation system.

Possibilities for renovation measures

Reporting of indoor climate investigations includes the recommendations for essential and urgent measures for renovation, for example poor operation of the ventilation and heating system, and the need for basic adjustment and cleaning of them. In the report, also other alternatives for improving the indoor climate in apartments are described. They include 2-3 alternative ways of repair of different quality and cost. These include, for example, equipping the apartments with simple outdoor air inlets (low level), heating of outdoor air with supply air heater or supplying it through a radiator (medium level), or installing of mechanical supply and exhaust ventilation system in every dwelling (high level).

Reporting of the method

Indoor climate investigation produces the basic data for the renovation. The guidelines include also lists of typical malfunctions of ventilation and heating system and their causes. Furthermore, they include the measurements and equipment used in the investigations as well as possibilities for measures of renovation. There are also instructions to the client on how to order the indoor climate investigation.

References

1.. Ruotsalainen, R., Ventilation, indoor air quality and human health and comfort in dwellings and day-care centers. (Doctoral Thesis). Helsinki University of Technology, Laboratory of Heating, Ventilating and Air Conditioning, Report Al, Espoo 1995.

2. Performance of ventilation systems in blocks of flats. (In Finnish Asuinrakennusten ilmanvaihtoselvitys). City of Helsinki 1993.

3. Building Renovation Program 1992-1996. Results of the development projects in the building sector. The Finnish Environment 119. 1997. (in Finnish)

4. Classification of Indoor Climate, Construction, and Finishing Materials. Finnish Society of Indoor Air Quality and Climate, FiSIAQ, FiSIAQ Publication 5 E, June 15, 1995, Espoo Finland.

Table 2. Typical indoor climate problems and their reasons.

Problem	Reason
Draught	too low room temperature - too low surface temperature - too high ventilation rate - high air supply velocity - too low supply air temperature - badly working or no fresh air inlets - air leakage - too narrow transfer air routes
Low room temperature	- unbalanced heat distribution system - wrong use - design failed - thermostatic valve do not work - clogged pipe - too high ventilation - insufficient or damaged heat insulation - leakage - too low supply air temperature
High room temperature temperature	- unbalanced heat distribution system - wrong use thermostatic valve do not work - solar radiation - warm spaces adjacent with dwelling (boiler room, laundry)
Unsteady room temperature	- untightly outer wall - unstable heat distribution system
Cold floor	- insufficient heat insulation - air leakage from joints between floor and wall - badly working fresh air inlets
Dry air	- low outdoor temperature too high ventilation rate - too high room temperature
Condensation on surfaces (also windows)	- insufficient ventilation - overpressure - insufficient heat insulation - furniture tightly in outer wall - humidifier - high humidity load in bathroom
Stuffiness	- insufficient ventilation high room temperature - high indoor humidity - too many habitant - odour emitting building material
Unpleasant odour	- sewer gases mould damage building materials
Odours from other dwellings and spaces	- leakage between dwellings, high pressure difference between dwellings - location of fresh air inlet
Noise	noise from ventilation system - noise from heating or water supply system poor sound insulation

CASE STUDY ON THE THERMAL COMFORT IN A SERIES OF STORES

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Abstract
This case study contains an extensive thermal analysis of the indoor climate and comfort in the establishments of a store chain, with a comparison between the opinion of the personnel and the physical reality and with an extensive analysis of the causes of the comfort problems.

Every store is settled in an industrial building without capacitive walls and without a ventilation or cooling system. There were strong complaints about overheating during summer and about cold and draught during winter. The study was made by means of a survey of the employees and by extensive measurements during summer and winter (May 1993 until April 1994) of temperatures and air velocities in all the stores. For our analysis of comfort we used the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) for the global thermal comfort and the Draught Rating (DR) for the percentage of dissatisfied due to draught. The values, calculated from the measurements confirmed the conclusions of the inquiry.

Simulation of the building showed that the strong overheating during summer was caused by the very high internal heat gains due to lighting. As the amount or type of lamps could not be changed, due to the marketing strategy of the store, the installation of a ventilation and cooling system appeared to be necessary. During winter, draught was caused by the bad construction of the entrance and exit locks for clients and trolleys. So reconstruction of these locks was necessary.

The applied strategy consisted of executing the necessary changes in one pilot establishment. These changes were evaluated in 1995 before applying them to the other establishments. To reduce the installation costs a combination of two ventilation/cooling systems was chosen: split units that cool the indoor air temperature and adaptation of already existing air groups that can mix indoor and outdoor air, so cooling can be minimised.

Also new entrance and exit locks were tested first in one establishment, to see if clients could manage them.
Keywords: comfort measurements, cooling, draught, overheating, store, survey, thermal comfort, ventilation.

1 Introduction

Since years the employees of the 6 establishments of an international store chain, complained about bad thermal comfort: globally too hot during summer and locally too cold and draught problems during winter. The internal heat gains are very high in all stores due to lighting, electrical equipment and the amount of clients. In none of the stores mechanical ventilation nor cooling was provided, except in the food section. There was only natural ventilation due to the air flows between the entrance and exit locks of the clients and the doors of the merchandise depots. The research is divided in a study of the summer situation and a study of the winter situation [1-3].

2 Description of the building

All stores have a similar structure: a ground floor with partly a high ceiling and partly a low ceiling, and a first floor with a smaller floor surface than the ground floor and a low floor-ceiling distance (3.10m). Fig. 1 gives a schematic plan of the buildings.

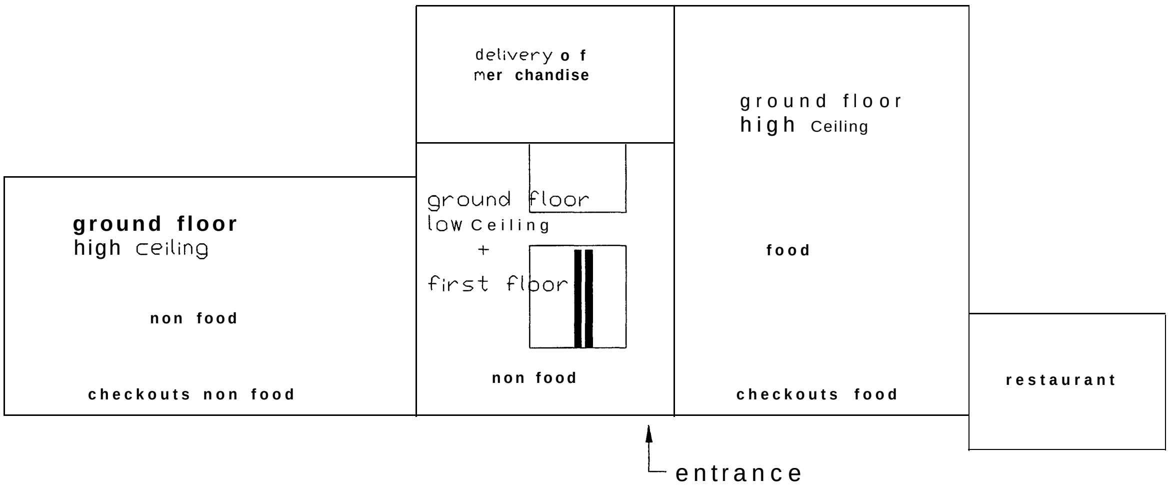

Fig. 1

3 Survey

In June 1993 a survey on thermal comfort was held in all stores of the company. Nearly 5 1% of the 3500 employees filled in a questionnaire. The specific comfort questions searched for the comfort judgement in summer and winter by means of two types of questions: questions on the general temperature impression during summer and winter and questions on local discomfort during winter at neck, back, legs, feet and head. For the judgement the psycho-physical voting scale of the ASHRAE comfort studies was used: +3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, - 1 = slightly cool, -2 = cool, -3 = cold.

The results of the survey formed the reference for the further analysis. They expressed a problematic comfort situation, both in summer and winter. The locations with strongest complaints differ for both seasons.

During summer there are general complaints of strong overheating, except in the food sections. In each store the differences between the sections are quite the same. Table 1 gives a summary of the results.

location	store 1	store2	store3	store4	store5	store6
1	2.44	1.93	2.88	3.00	2.94	3.00
2	1.14	2.45	2.08	2.39	2.59	2.24
3	-0.11	0.07	0.00	-0.24	0.18	-0.06

Table 1: mean values of the general temperature impression during summer (1=first floor; 2=non food ground floor; 3=food ground floor)

In winter the complaints are mainly about cold and draught. Table 2 gives a summary for all stores for the general temperature impression and for the draught impression.

location	store 1	store2	store3	store4	store5	store6
general temperature impression during winter						
1	-1.45	-1.03	-1.37	-1.23	-0.63	-1.21
2	-0.62	0.40	-0.18	0.05	0.05	0.00
3	0.28	-0.64	1.04	0.95	0.33	0.59
draught impression during winter						
1	-1.34	-1.35	-1.37	-1.29	-1.05	-1.05
2	-0.42	-0.07	-0.31	-0.12	-0.10	-0.32
3	0.40	-0.46	0.63	0.64	-0.28	0.47

Table 2: mean values of the general temperature impression and draught impression during winter (1=food, checkouts and merchandise delivery; 2=general services and non food ground floor; 3=first floor)

4 Measurements and calculations

4.1 Measurements

Through measurements of the indoor climate, we looked for a confirmation of the survey and a specification of the causes of the thermal discomfort. The measuring campaign consists of two parts: continuous temperature measurements during a longer period and short-term measurements with a comfort apparatus at different places.

4.1.1 Continuous measurements

In summer, the continuous measurements are made in 2 establishments on the first floor ($420m^2$) during 7 to 8 weeks. It concerns measurements of surface temperatures on the floor, walls, false ceiling and roof, temperature gradients for two heights and air temperatures at 13 different places at the height of 1.80m (head level).

In winter, the continuous measurements are made in 2 establishments at the checkouts during 10 weeks. Air temperatures are measured at foot level, back level, neck level and head level.

4.1.2 Short-term measurements

In each store, short-term measurements are made with a comfort apparatus from Brüel & Kjaer: it is a portable tripod with 4 small measuring instruments, that register every 10 sec. the air temperature, the radiant temperature of two hemispheres, the relative humidity and the air velocity (mean value and standard deviation over 10 sec). In the summer period, we measured at 4 to 5 places, each time during a day or a week and the measurements are averaged per 10 minutes; in the winter period, measurements are made at 10 to 11 places, each time during a few hours and are averaged every minute to get a clear picture of the fluctuating character of the indoor climate.

4.2 Principles of the applied calculation method

4.2.1 Global thermal comfort

To judge global thermal comfort, we used the thermal comfort theory, developed by Fanger [4]. He deduced the thermal index ‘Predicted Mean Vote’ (PMV), which takes into account the air and radiant temperature, the relative humidity, the air velocity: mean value and turbulence, the activity level (metabolism) and the clo-value: measure of the thermal quality of the clothing. This thermal index is connected to the frequently used ASHRAE-scale (see above). By measuring the climatic parameters and assuming the activity level and the clo-value for a certain situation, the PMV can be calculated for that situation. Connected to the PMV-value, Fanger uses a more comprehensible index, the ‘Predicted Percentage of Dissatisfied’ (PPD). A situation is considered acceptable if it does not exceed a maximum of 10 % of dissatisfied persons (PMV = -0.5 to +0.5).

4.2.2 Draught

Fanger et all [5] also developed a model to quantify the draught risk by the thermal index ‘Draught Rating’ (DR). Determining parameters are the air temperature, the air velocity and the air turbulence, from which the air turbulence is the most important. Studies showed that a fluctuating air velocity, although with a low mean value, is experienced as much more uncomfortable than a constant, higher air velocity due to the constantly fluctuating cooling of the body [5-8]. Therefore it is possible that, based on the mean air velocity, thermal comfort seems to be acceptable, but that, due to too high fluctuations, the percentage of dissatisfied because of draught, is unacceptably high.

4.3 Building simulations

With the building simulation program CAPSOL [10], we simulated the thermal indoor climate during summer for the non food sections of the different stores. Outdoor climate is the month of July from the TRY-year for Ukkel (near Brussels). Aim was to analyse the influence of the internal heat gains due to lighting, electrical equipment and clients versus the influence of solar gains on the overheating.

Table 3 gives per store the internal heat gains due to lighting and electrical equipment with the distribution for the different zones and the mean daily amount of clients. Each client represents on average 120 Watt. For the simulations the mean daily amount of clients is transformed into an hourly amount by a weight factor.

establishment	ground floor high ceiling [kW]	ground floor low ceiling [kW]	first floor [kW]	clients [amount/day]
1		68.1	108.9	5100
2		95.2	61.4	5050
3	100.2	54.6	83.1	5600
4	55.7	43.3	91.6	3300
5	115.5	96.9	53.7	5600
6	92.1	62.1	81.4	2400

Table **3:** internal heat gains with distribution over the different zones and daily amount of clients per establishment

We first simulated each building without internal heat gains. Although there are differences between the stores, a global tendency can be observed: when there are no internal heat gains (IHG), there is a very strong fall of the indoor temperature: at the ground floor the temperature never > 24°C; at the first floor the temperature without IHG almost never > 26°C, whereas with IHG the temperature often > 30°C.

To analyse the influence of solar gains, we compared the stores with very few windows in the shopping zone, with the stores with much more windows. Comparing them for IHG = 0 does not show a considerable difference. This demonstrates the minor role of solar gains on the indoor climate.

The winter situation is not simulated. The constantly changing interaction between indoor and outdoor climate through the entrance and exit locks creates a very complex situation that hardly can be simulated in a correct way.

5 Discussion

5.1 Comparing survey - measurements

Comparing the results of the measurements with the survey, we notice that for the summer situation similar trends are found in both calculations and survey. Nevertheless for some sections, there was a discrepancy between the survey and the calculations. This is probably due to the lack of thermal comfort of many years that the employees wanted to emphasise by giving a higher (more negative) vote than can be observed in reality. Another reason can be the radiant temperature of the ceiling. It may be assumed that this temperature is much higher than the floor temperature due to the great amount of lamps. By calculation we found for the ceiling a mean temperature of 29,4°C, whereas we measured a mean radiant temperature (average of floor and ceiling) of 26°C. The effect of this higher ceiling temperature is not included in the calculated PMV values, but will affect the thermal comfort negatively, especially with the low floor-ceiling distance.

For the winter situation there is a greater difference between the results of the survey and those of the measurements. For locations with higher temperatures, both in the survey and the measurements the distinction is made between the thermal situation ("neutral") and the draught situation (mostly unacceptable: > 10 to 15%). For locations with lower temperatures, the agreement between survey and measurements is less: the measurements show an acceptable thermal situation and an unacceptable draught situation, whereas the employees consider both the thermal and the draught situation as unacceptable. It is notably that for 60% of these locations, the percentage of dissatisfied due to temperature from the survey, agrees very well with the calculated draught rating. This confirms the assumption that people not always distinguish between the sensation of high fluctuating air velocities and the sensation of low temperatures, because of their similarity (a local cold feeling).

The analysis shows that during winter, there is a draught problem and not so much a temperature problem, especially near the entrance and exit locks of clients and merchandise. So solutions have to be searched in stopping these turbulent draught flows.

5.2 **Solutions**

5.2.1 Proposals

For the summer situation, all results show that the high internal heat gains cause the strong heating up of the building. But because of the very strict requirements for colour reproduction and light intensity, asked by the company, only extraction of the ventilation air through the lamps, to remove the convective part of the heat emission by the lamp, was a possibility to reduce the cooling load.

So the preferential solution is forced and controlled ventilation with fresh air. We analysed the possibilities of night-ventilation, of day- and night-ventilation and the effect of the magnitude of the ventilation rate. To avoid complaints of draught the ventilation rate has to be restricted during working hours, whereas for night ventilation, simulation shows that the efficiency increases very slowly once the ventilation rate exceeds 3.5/hour. Furthermore a higher rate includes higher energy use. So for further calculations we only considered the following ventilation rates: day-ventilation = 2. S/hour; night-ventilation = 3. S/hour.

Night-ventilation already improves the thermal comfort, but not sufficiently. Due to the high internal heat gains and the lack of heat capacity in the building, the building heats up quickly during the day. Day-ventilation contributes much more efficiently to the decrease of the indoor temperature. The simulation showed a remarkable improvement of the thermal comfort by a combination of day- and night-ventilation. **Only** on the first floor, even with day- and night-ventilation, we still get temperatures above 28°C. So additional cooling has to be considered.

During winter the problems are caused by too strong draught flows near the entrance and exit locks. The proposed solution consists of rebuilding the locks to break the draught current towards the checkouts.

5.2.2 Evaluation

Both for the summer and the winter situation, a store was chosen as pilot-project to realise the proposed solutions and to evaluate them, before the application in all other stores.

Considering our results, an independent consultancy office worked out a configuration with two types of ventilation systems. On the first floor the space is divided in different zones, each with one or more split- or air-groups with one suction opening and several blow-in openings. The split-groups, that suck in indoor air, cool it and blow it back into the room, are cheaper to install, but use more energy than the air-groups, that mix fresh air with indoor air to minimise the cooling load. For the air-groups they used existing groups that were passed into disuse. By using outside air, the energy use will be reduced, but the installation and maintenance costs are higher than for the split-groups.

With continuous and short-time measurements we analysed the improvement of the thermal comfort and compared the homogeneity of the temperature field of both ventilation systems. Continuous measurements are done on the first floor in one zone with a split-group and one zone with an air-group. We measured the air temperature under a blow-in opening, between two blow-in openings and on a location as far as possible from a blow-in opening. At the same time we measured on 23 locations with the comfort apparatus.

These measurements showed that the ventilation system realises a decrease of the PMV and PPD. Table 4 gives a summary for the first floor.

	present situation	original situation	difference
PMV [-]	1.14 - 1.47	1.63 - 1.83	0.36 - 0.48
PPD [%]	33.7 - 49.7	57.3 - 67.5	17.8 - 23.6
DR [%]	7.2	4.5	-2.7

Table 4: Comparison between original and improved comfort situation

Both systems are adjusted for a blow-in temperature of 21°C. The mean air temperature decreases from 27°C to 22.3°C. The radiant temperature decreases from 27°C to 23.3°C. As table 4 shows, the PMV decreased with 0.42. So comfort improvement has been realised, but it is still not optimal due to the rather high radiant temperature and the rather high activity level of the employees.

Analysing the homogeneity of the zones, we find that both ventilation systems create a very homogenous temperature field. Also from a comfort point of view, we find very little difference between both ventilation systems. Table 5 gives a summary of the air temperature, the PMV, PPD and DR averaged for the zones with split-groups and the zones with air-groups.

metabol =2 1 OW	air-group		split-group	
clo-value = 0.8	on top	on floor	on top	on floor
temp [°C]	23.0	22.3	22.1	22.0
PMV [-]	1.39	1.33	1.32	1.29
PPD [%]	44.2	41.9	41.8	40.6
DR [%]	10.0	10.5	10.3	11.0

Table 5: averaged comfort values for the air-groups and the split-groups

To solve the draught problems during winter they installed in one establishment new entrance and exit locks, so that there is never a direct connection between the indoor and outdoor climate. They did not ask us to do new measurements, which probably means that there were no complaints anymore.

6 Conclusions

A very extensive comfort research was done by means of a survey, measurements and building simulations. The survey formed the most important part of the research. The measurements however confirmed the results of the survey: strong overheating during summer and local draught problems during winter. The measurements and building simulations were necessary to deduce the causes of the thermal discomfort. It showed us the importance of the internal heat gains for the overheating during summer, the influence of the ceiling radiant temperature and the need for a ventilation system. It also proved the difficulty for people to distinguish between temperature problems and draught problems.

The proposed solutions were evaluated after installation in one store. They realised an improvement of the thermal comfort, but did not give complete satisfaction for some problems. It is up to the company now to apply the improvements in the other stores and to evaluate the judgement of the employees on the new situation.

7 References

1. Verbeeck, G. And Hens, H. (1993) *Comfortstudie MAKRO verslag zomersituatie Report 93/7 Project G043.*
2. Verbeeck, G. And Hens, H. (1994) *Comfortstudie MAKRO verslag wintersituatie Report 93/7 Project G043.*
3. Verbeeck, G. And Hens, H. (1995) *Comfortstudie MAKRO St Pieters Leeuw verslag vergelijkende metingen en evaluatie comfortverbetering Report 95/1* **4** *Project* **G043.**
4. Fanger, P. 0. (1970) *Thermal Comfort. Analysis and Applications in Environmental Engineering,* McGraw-Hill.
5. Fanger, P.O., Melikov, A.K., Hanzawa, H. and Ring, J. (1988) Air Turbulence and Sensation of Draught. *Energy and Buildings,* 12, pp 21-39.
6. Mayer, E. (1985) Untersuchungen von Zugerscheinungen mit Hilfe physikalischer Meβmethoden. *Gesundheits-Ingenieur,* 106 Heft 2. pp 65-73.
7. Mayer, E. (1989) Thermische Behaglichkeit in Raumen Neue Beurteilungs- und Meβmoglichkeiten. *Gesundheits-Ingenieur,* 110 Heft 1. pp 3 5-43.
8. Mayer, E. (1990) Thermische Behaglichkeit Einfluβ der Luftbewegung auf das Arbeiten im Reinraum. *Reinraumtechnik,* **4** Heft 6. pp 3 O-34.
9. TC 156/WG 6. 1994. *Progress Report to TC 156 from WG 6 Design criteria for the Indoor Environment.* Document TC 156/WG 6.
1 O.CAPSOL computer software to calculate multizonal transient heat transfer. PHYSIBEL software, Maldegem, Belgium

Environmental and energetic advantages of solar-collector

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Abstract

The solar-collector can be integrated into the roof-structure or subsequently onto flat or inclined roofs. Their aesthetic forms are fitting well to any building. The solar-collector analysed by us (product of the company Fiorentini Hungary) is designed to be integrated into roof-top place. The connecting pipes are hidden, remaining behind the collector.

The solar-collector can operate with air and water heat transfer fluid, separately or in common operating mode. Thus, the thermal energy of solar radiation can be used for domestic hot water applications and for different technological purposes as well (like grain drying).

Generally, the lavatories and baths are ventilated by fan in negative pressure. Using wintertime the solar-collector in air-based operation, heated auxiliary air is introduced into the house. During the collector's thermal examination in air, water and common operating mode, we could perform measurements and determine, on the base of the results, the capacity and efficiency in every case.

The application of solar-collector has multiple advantages: using solar energy we can save other resources, but in the same time the contaminant emission of unburned combustibles is reduced, producing therefore less pollution.

Generally, in case of solar-collector application, only the refunding of investments are taken into account, leaving without attention the environmental advantages, which have no direct influence to the expenses.

Keywords: efficiency, energy saving, solar-collector

1 Introduction

The utilisation of solar energy is influenced not only by geographical place, orientation and settle place, but the efficiency and operating parameters are important factors as well. The determination of efficiency and performance were the primary purposes during of our measurements. We were testing the influence of heat transfer fluid flow rate variation onto the efficiency and thermal performances of solar-collector.

2 Methods

The collector had westward orientation with a tilt angle of 45° during of our measurements. This angle is corresponding to a typical roof inclination. The useful surface of the solar-collector is A=1,6 m^2. The measurements were performed when the heat transfer fluid was: air, water, air and water.

During the examination, we were measuring the following parameters:

- atmospheric air temperature
- air velocity
- intensity of solar irradiation onto a horizontal surface (I, W/m^2)
- entry water temperature(t_{we}, °C)
- outlet water temperature(t_{wo}, °C)
- entry air temperature(t_{ae}, °C)
- outlet air temperature(t_{ao}, °C)
- air volume-flow ($\dot{V}_a$, m^3/h)
- water volume-flow ($\dot{V}_w$, lit/h)

The air and water temperature was measured by a resistance thermometer with 8 channels. The intensity of solar irradiation perpendicular to the collector surface was determined by calculations ($\dot{q}_{tot}$, W/m^2), using the results of measurements.

The collector was examined in cross-flow operating. In water-based operation mode, city water was introduced into the collector. The volume-flow was measured by water-meter and volume-meter, the air-flow rate by measuring orifice. The connection scheme of the measurement is represented on Figure **1.**

3. **Results**

Because of Earth rotation, during the measurements, the solar-irradiance intensity was varying **continuously.** Partially this is true for the atmospheric air temperature as well. During the evaluations, we were considering the „quasi-stationary" states and values around the maximum solar-irradiance ($\dot{q}_{tot}$) at the known orientation.

The efficiency of collector, corresponding to our results, is:

$$\eta = \frac{\dot{Q}}{A \cdot \dot{q}_{tot}}$$

Where: $\dot{Q}$ [W] - the transferred heat flow rate to the air and water heat transfer fluids.

The maximum efficiency and capacity of the solar-collector in different operating modes, based on the results, are the followings:

1. Water based operation mode:
   – capacity: 1070-1190 W
   – efficiency : 62-74%
2. Air based operation mode:
   – capacity: 260420 W
   – efficiency : 30-47%
3. Water and air, common operation mode:
   – capacity: 300-910 W
   – efficiency : 38-56%

We were determining the collector performance and efficiency at various water and air heat transfer fluid flow-rates. The influence of water flow variation onto the performance and efficiency of the solar-collector is represented on fig 2. The fig. 3. represents the influence of air heat transfer fluid.

4. **Conclusion**

The use of solar-collector is favourable in both, air and water operating modes. In the commercial distribution, these solar-collectors are classified with good performances. In the range of examined volume-flow the water was heated from 20°C to 34°C, in case of air the temperature increased from 28°C to 57°C which is suitable for technological purposes (like grain drying).

References

1. Erdõsi I. - Kajtar L. - Bánhidi L. (1997) Thermal comfort in climatized office Buildings, Healthy Buildings / IAQ '97 vol. 2. 207-213 p. Washington, USA.
2. Kajtar L. - Bánhidi L. (1996) Effect of the external air pollution on indoor air quality and selecting mechanical ventilation system, The 7th International Conference on Indoor Air Quality and Climate. Vol. 2. 211-216 p. Nagoya, Japan.
3. Kajtar L. (1992) Thermal comfort dimensioning and results of measurements in underground spaces, The 5th International Conference on Underground Space and Earth Sheltered Structures. Proceeding 353-360 p. Delft, Netherlands.

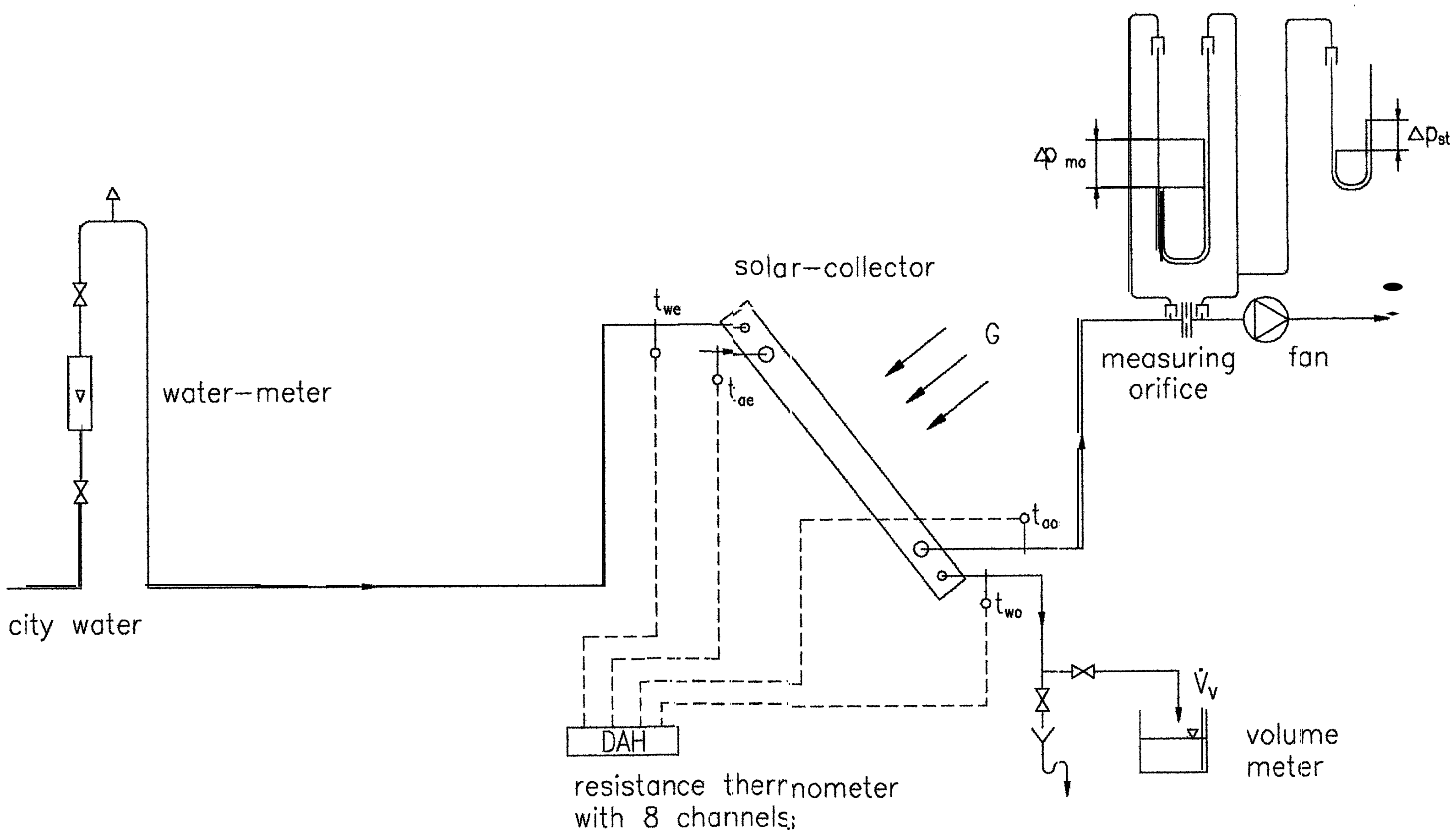
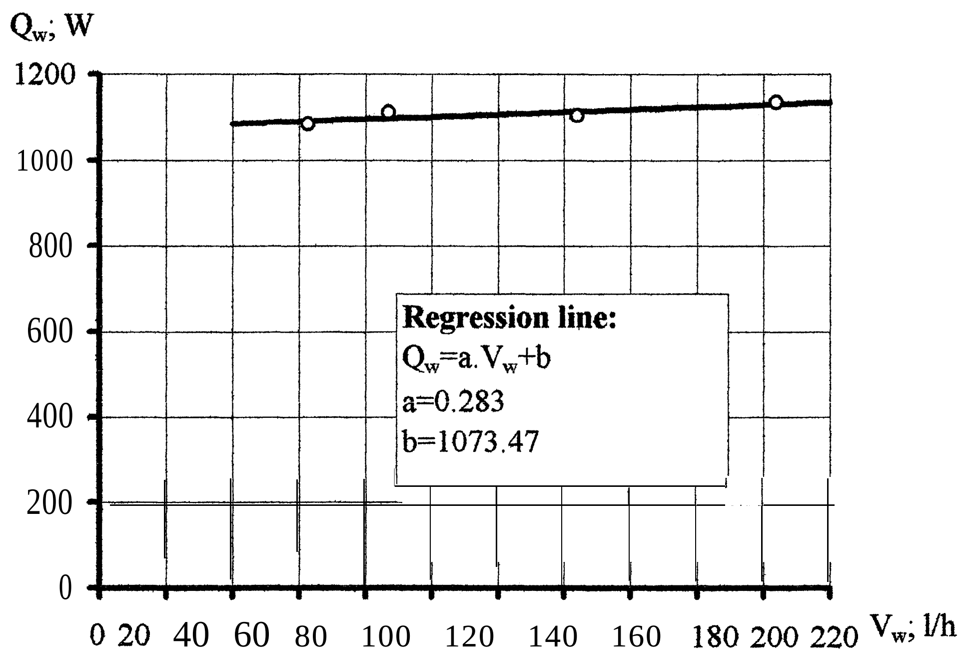


Figure 1. Connection scheme



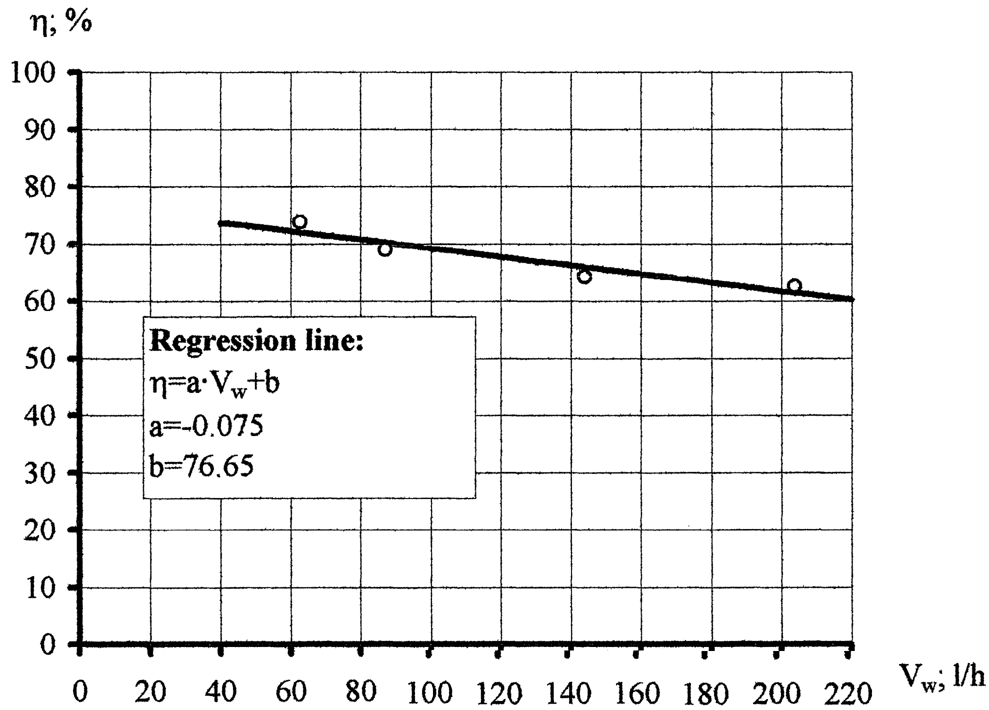
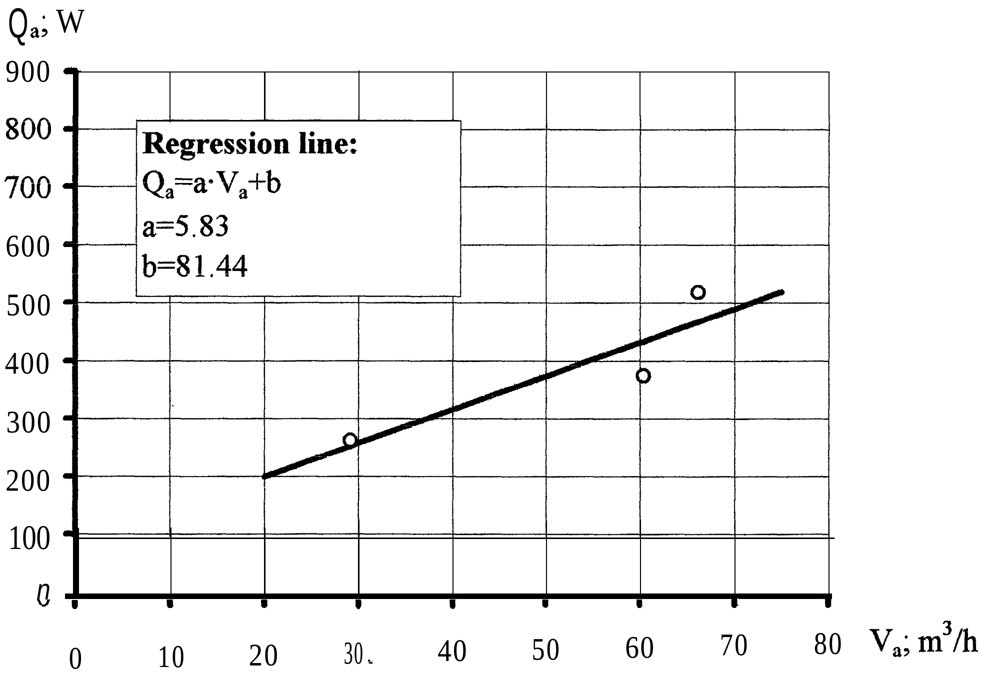


Figure 2. Capacity and efficiency of solar-collector in water-based operating mode



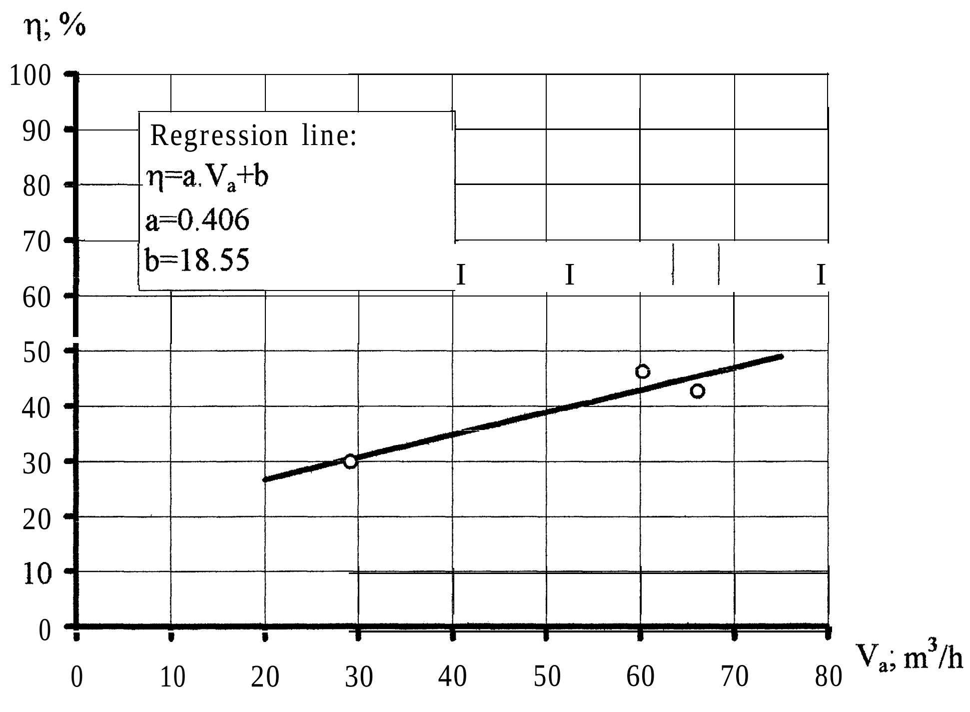


Figure 3. Capacity and efficiency of solar-collector in air-based operating mode

The opportunity of indoor environment performances improvement - component of the sustainable development

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Abstract
The requirements and performance criteria concerning the indoor environment are in a permanent development due to the increase of : users needs, outdoor environment degradation and constructive systems development.

From the sustainable development viewpoint, the quality level of a building includes the capacity to be permanently adapted to the new requirements through rehabilitation measures.

The paper is based on a study results on the indoor climate and energy consumption of a hostel building at which thermal rehabilitation works were carried out without any intervention on the natural ventilation system.
Keywords : Requirements performances, sustainable development, thermal rehabilitation

1 Introduction

The modern rehabilitation of buildings in Central and Eastern European countries is a stringent issue that presents an actual interest.

As in the Eastern side of Germany many buildings should be subjected to a large improvement operations concerning :

- energy conservation ;
- environment protection ;
- meeting all requirements concerning the sustainable development.

This operation will last for a few decades and will need large investments. This is why it is very important that the adopted solutions be well designed.

Now we realise that for a sustainable development, buildings should be designed for being periodically adapted to the requirements which result from the social, economical and technical progress [1].

The alternative should be that the buildings utilisation time to be reduced as in the case of all the other industrial products. After demolition, many materials would be used as raw materials transformed and reused.

It seems that the present and future economical situation doesn't allow this, and buildings must be used as long as their structure still satisfies the safety requirement.

At least once they can be strengthened.

In Romania, this last aspect is very important due to the periodicity of intense earthquakes (20...30 years). An additional element of difficulty comes out compared to the eastern side of Germany. For the moment, there is a tendency to pay attention especially to the safety problem against mechanical action and recently the thermal rehabilitation for energy conservation diminution of CO, emissions begins to be considered.

It that really enough ?

This problem is being discussed in the paper.

The opportunity was the restoration of a students hostel building. It has 5 levels and was built 30 years ago using reinforced concrete prefabricated panels.

Two intense earthquakes, the periodical variations of temperature and humidity, the corrosion and the infiltration at joints required the restoration.

2 General presentation of the building before and after the restoration

The analysed building is a students' hostel with the capacity of 300 places, made of reinforced concrete prefabricate panels, Figure 1.

The external walls have a sandwich structure, with thermal insulation core, made of cellular light concrete and a high percentage of thermal bridges. The external walls as well as the flat roof have ensured an insufficient degree of thermal insulation.

The heating achieved through the connection to the district heating system didn't allow the control and the monitoring of power consumption.

The thermal rehabilitation had in view:

- the additional thermal rehabilitation of the external walls and flat roof ;

• the increase of thermal protection degree of windows through the setting of an additional glazing in 50% of the number of the windows ;
• the use on the longitudinal façades of bow-windows which cover the rest of 50% of windows that play the role of solar energy collectors in a passive system and also the limitation of wind effects ;
• thermal insulation of the basement with expanded polystyrene protected by a concrete layer;
• the optimization of heating equipment working.

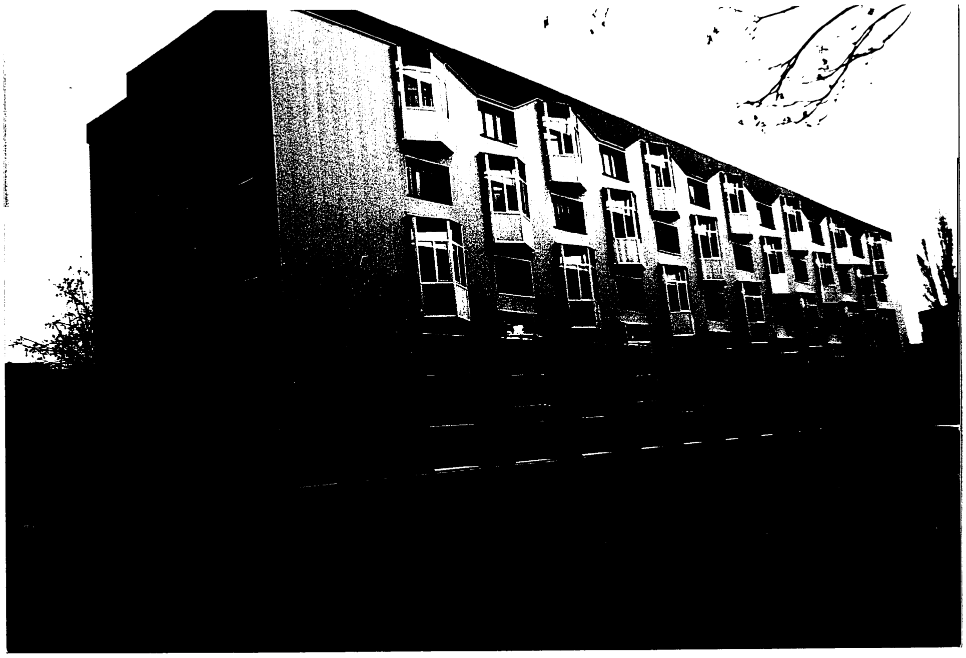

Fig. 1 General view of the students' hostel after the restoration

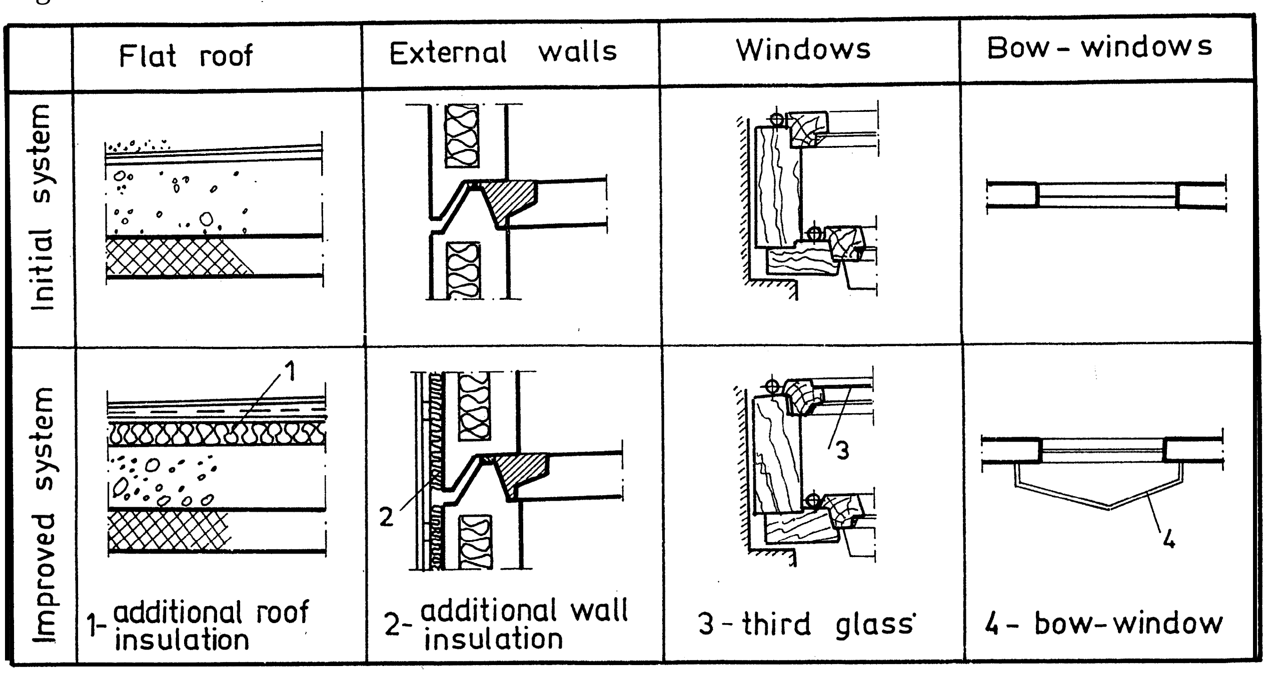

Fig.2 Constructive solution for envelope elements

The constructive solutions for the envelope elements before and after the rehabilitation are schematically presented in Figure 2 [2]. An optimal air composition is ensured through unorganized natural ventilation.

3 Effects of thermal rehabilitation on power consumption and indoor environment

As a result of thermal rehabilitation works, a decrease of power consumption for heating is estimated about 60%, this is reflected in the diminution of the value of specific power consumption index from 351,92 kwh/m² year to 127,55 kwh/m² year.

Measurements of indoor environment parameters were made simultaneously in the thermal rehabilitated hostel before being exploited and also, in two other similar hostels with no interventions for improvement, these measurements made during the winter of 1997 emphasised the following aspects :

- the air temperature in the thermal rehabilitated hostel had values with 3...9° C higher than those in the other uninsulated buildings ;
- the air temperature in the thermal rehabilitated hostel had close values, in all rooms, no matter of orientation in plane or vertical position ;
- the temperature on the inside surface of external walls is cvasiuniform, which shows that the unfavourable effects of thermal bridges were eliminated ;
- the relative air humidity in the rehabilitated hostel is clearly inferior compared to that in the other hostels. This is explained by the vapours emissions caused by the exploitation process.

The positive effects of rehabilitation works were obvious also in the results of determinations made in the periods, without heating system operating, there were recorded constantly temperature values for indoor air of about 20...21° C, when the mean outdoor temperature had values of about 4... 12° C.

4 Particularities of the exploitation regime and natural ventilation

The degree of occupancy of one room, with a 42 m² volume, is of 3 students. This number is in accordance with sanitary regulations.

The average period of occupancy is estimated, based on surveys, to 50 person · hours/day.

The necessary fresh-air flow rate for dormitories, recommended by regulations of different countries, varies between 11 and 30 m^3/h for every person [3]. This implies that for our case, the ventilation rate will vary between 0,78 and 2,14 h^{-1}.

Considering the adopted ventilated system, the refreshment of the indoor air will be made through air infiltrations caused by the leaks in carpentry and periodic opening of the window. In the cold period of the year, during the night, the ventilation will be made exclusively by air infiltration through carpentry leaks, under the influence of thermal air draft and especially of the mind pressure. In that case the estimated values of air flow rate and ventilation rate are presented in the tables 1 and 2.

It is observed that air mobility is due exclusively to wind pressure, the ventilation being totally insufficient at the wind speed below 4 m/s for rooms without bow-window and under 15 m/s for rooms with bow-window.

Temperature difference (T_i-T_e) [°C]	Thermal pressure difference Δp [Pa]	Before the renovation		After the renovation (in rooms with bow-window)	
		air draft [m³/h]	ventilation rate [h⁻¹]	air draft [m³/h]	ventilation rate [h⁻¹]
10	3,00	7,37	0,175	2,09	0,069
15	4,48	9,64	0,230	3,84	1,530
20	5,98	11,70	0,280	4,66	1,860
25	7,48	13,59	0,320	2,98	1,190
30	8,97	15,35	0,370	3,57	1,420
35	10,46	17,05	0,400	4,17	1,660
40	11,96	18,62	0,440	4,77	1,900

Table 1 Air change from stack effect

Wind speed w [m/s]	Pressure caused by the wind Δp (w) [Pa]	Before the renovation		After the renovation (in rooms with bow-window)	
		air draft [m³/h]	ventilation rate [h⁻¹]	air draft [m³/h]	ventilation rate [h⁻¹]
4	13	20,00	0,47	5,68	0,13
6	29	33,71	0,80	9,58	0,23
8	51	49,20	1,17	14,00	0,33
10	80	66,53	1,58	18,92	0,45
12	115	84,80	2,02	24,11	0,57
15	180	114,55	2,72	32,57	0,77
18	260	146,55	3,48	41,67	1,00

Table 2 Air change from wind pressure

The redesigning of the ventilation system will take account of setting of admission holes on the façade and of discharge openings are equipped in the stair cage. These openings are equipped with ventilators (Figure 3), that are designed to ensure the minimum ventilation degree even in the most disadvantageous exterior conditions [4].

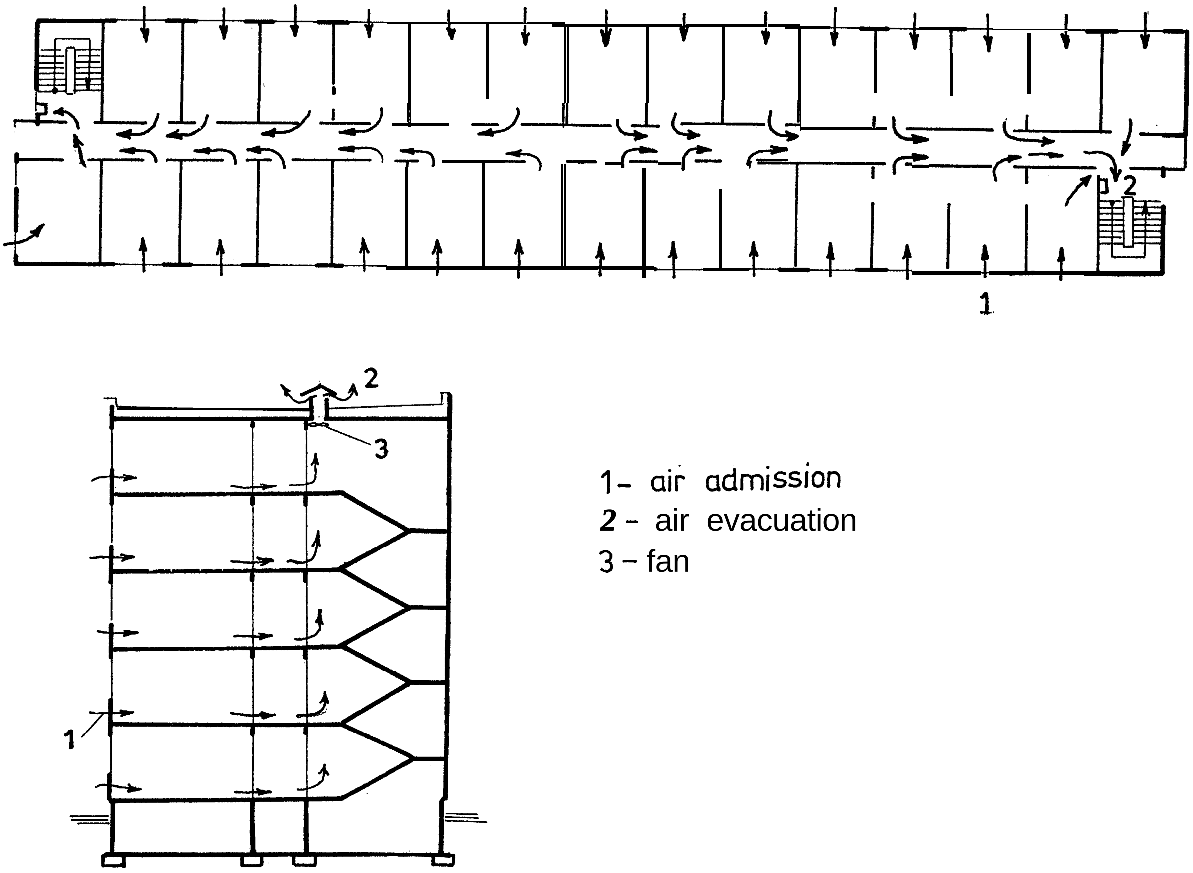

Figure 3 Suggestion for the ventilation system

5 Conclusions

On the list of qualities that have to be fulfilled by a building, the capacity of performance improvement occupies a top rarik, if we consider the criterion of sustainable development.

From the analysis of a real case of thermal rehabilitation of a building, there results the degree of accomplishment of this condition by the existent buildings.

The concept of rehabilitation must consider all the aspects related to the exploitation particularities and the quality of indoor environment.

6 References

1. Angioletti, R., Goben, C., Weckstein M., Durand, E. (1996) Vingt-quatre critères pour concevoir et construire un bâtiment dans une logique de développement durable. ***Cahiers du CSTB, No. 2864***

2. Radu, A., Bliuc, I., Baran, I., Orhei C. (1997) Thermal rehabilitation of a building from prefabricated great panels as a contribution for a sustainable development. *XXVth IAHS World Housing Congress - Emphasizing Eastern Europe,* Sinaia, Romania
3. Clauzel, D. (1988) Besoins en aération. *Energétique des Bâtiments,* vol I, Paris
4. Roulet, C.-A. (1995) Building energy savings and indoor air quality. *Energy Labelling for Southern Europe Countries,* Sevilla

The Human Olfactory System
Implications on Hormones Concerning Perception of VOC

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Abstract

Chemical substances like volatile organic compounds (VOC) in the indoor environment have been accused to be responsible for sick building syndrome (SBS), loss of tolerance and asthma among other annoying effects. But there are few explanations of the process in which low VOC concentrations can cause severe disturbances in the human body.

Humans can detect very low VOC concentrations through the olfactory system in the nose and sometimes percept this as a limited smell, but the effect on the body can be more influential in a longer perspective.

This paper tries to assess some of the existing knowledge of the specific process pattern that starts in building physics (emissions) and goes through structure biochemistry (VOC molecules), neurology (of the nose) and ends in endocrinology (hormone effects), immunology (tolerance) and probable human illness.

The approach is to follow a specific VOC molecule through a sequential theoretical study of the interaction between building and man. A possible way to describe the interaction and the effects of signal interference of chemical compounds like VOC on humans, can be summarized by the following hypothesis on how VOC would be perceptible but also misinterpreted by the olfactory system and the brain.

1. Chemical reactions with VOC can produce numerous unwanted chemicals indoors.
2. VOC molecules are chemical signals in the indoor air approaching the body.
3. VOC blends are signal patterns that involves information and the olfactory system collects this information about the situation outside the body and distribute it as molecular image patterns to different centres in the body.
4. Hormone reactions to these signals can make us sick. The outcome depends on how the brain interpret the signals from some of these molecules because they have points of similarity with other compounds in nature.

This paper can hopefully be of use as a interdisciplinary bridge, in the further detailed investigations of SBS and also give some clues to the connections between VOC, dampness, smell and illness to scientists working with healthy houses, ventilation and materials technology.

Keywords: Olfactory, hormones, volatile organic compound VOC,
sick building syndrome SBS, humidity, smell, signal molecule images

1. Introduction

The olfactory system is a sensory system in the body specialized in detection, discrimination and identification of odorous compounds (1). Sensors are situated in the nose and can be compared to antennas receiving chemical signals from the environment. The olfactory system is probably the principle perception system for VOC.

VOC and odorous compounds would influence our everyday life, due to the reactions that our body would implement and the kind of messages it perceives, as results of interaction between the sensors and these chemicals. In this paper VOC molecules would be seen as signal molecules approaching the body from the outside (1, 2).

Two groups of signalling molecules inside the body that has great influence on our health are hormones (3) and cytokines (4). Some investigations state that VOC can mimic hormones (5). Building physicists with the knowledge about forces of change inside the building envelope (on molecules from VOC), structure biochemists with their knowledge of molecule surfaces (on molecules from VOC), neurologists with their knowledge about the transfer of electro chemical information (on molecules from VOC) through the neuron pathways, endocrinologists with the knowledge of hormone reactions in the body (on molecules from VOC), might need a common “language of VOC” to work out the final answer. Such a VOC signal language is proposed here.

This paper tries to focus on some of the scientifically accepted grounds that could be of help for further investigations. There is also an ambition to stimulate abstract thinking in new “pictures” that hopefully would give us more of a creative space and invite new scientists to this interdisciplinary field.

2. Chemical gas reactions in the indoor air and VOC

The perception of VOC is in principle an electro chemical reaction pattern which starts with a specific VOC molecule or a blend of different VOC molecules floating around in the indoor air. These molecules can be original emissions or reaction products from chemical gas reactions in the indoor air. VOC related gas ***reactions will be stimulated by*** at least three important factors, lots of raw material, favourable air conditions and energy.

¤***VOC emissions (raw material)*** could come from intake of ventilation air but outdoor air for ventilation has improved since the implementation of environmental regulations. In USA, investigations shows that out of hundreds of air pollutants covered under the existing US laws, only ozone and sulfurdioxid is more prevalent outdoors than indoors (6). All of these air pollutants are not VOCs and there is also VOCs that is not covered by US law. Measurements in the indoor air has identified more than 900 VOC (7). So where does all this VOC molecules come from ?

Raw materials in the shape of VOCs are essential for gas reactions and there are more than 45.000 building products for sale in Sweden today with a lot of known and unknown VOC and other compounds included (8), that could support reactions. Other VOC sources are furnishing and equipment that might be needed to use the building as a home or place of work. The procedure of maintenance with cleaning agents, wax and other different chemicals is also a source. Tobacco smoke is still another source of about 4000 chemical compounds and some of these are VOC (6).

An uncontrollable source of chemical compounds would be everything that we on a daily

To be able to analyse and understand how different chemical compounds, natural molecules as well as emission molecules and molecules produced by chemical reactions in the indoor environment, interact with humans, we have to take a closer look at the input systems where the interaction starts. The olfactory system (nose), the omalfactory system (eye), the respiratory system (lungs), the digestive system (stomach) and the skin system can be involved in these interactions.As the nose probably is the principle perception organ for VOC molecules and other molecules in the air we will concentrate this paper on the olfactory system, but that does not mean that the other input systems is negligible .

3. A brief description of the human olfactory system

To begin to understand the concept of smell, we have to consider the neurology of the nose and its physiological organ ***the olfactory system.*** The primary function of the olfactory system (olfaction is smell) is to signal to *the brain* via *the nervous system,* a change in its chemical environment (for example the presence of VOC molecules in the indoor air). This function can be important for escape reflexes, internal physiological regulation of the body and stimulation of different social behaviour (15, 20).

The principal parts of the olfactory system and its pathways for signals to important centres in the brain can be described as we follow a signal molecule.

The part of the olfactory system that interacts with the air molecules in the surrounding environment is called *the olfactory mucousa.* Its a layer 5 cm2 in the upper part of the nose cavity, where *odourant molecules* in the air meet with *odourant binding protein molecules.* (16). This area is used for detection of molecules in the air.

There is another layer 1 cm2 at the floor of the nose cavity, called *the vomeronasal organ* where molecules in liquid phase meet their binding molecules. Its not completely proven what this area is used for in humans, but a hypothesis is that its primary function is for detection of sexual pheromones. This is what most animal uses it for (14) so the hypothesis is not so improbable. There is evidence of human pheromones (17).

If the active surfaces *domain* on the odourant molecule and the domain of one of the odourant binding protein molecules would fit when they meet, the two molecules bind together. The odourent molecule would be transported by the binding molecule *(the odourant binding protein)* to a special target surface, *the olfactory receptor protein* (16). This receptor is placed on a *cilia* that is a part of an *olfactory receptor neuron cell (ORC)* (16). The number of ORCs is unknown for humans. Rabbits may have 100 millions (20).

When the effective domain area on odourant molecule is properly connected to the target surface on the cilia, the receptor ***transmits*** a chemical signal downstream the ORC (1) to the *olfactory knob* , where chemical signals from many cilias would be mixed to an electric field pattern, that is ***the molecular image*** of the particular VOC molecule (1). This image would be sent together with all the other presented molecule images to a collection point *the glomeruli* and electric field filter station, *the olfactory bulb* (20,21).

Its very difficult to describe all the system functions of the olfactory bulb and what it does with all the electrical signals that reaches its input areas *the glomeruli.* It is possible to use a metaphor with a technological system that readers from the engineering disciplines are more familiar with, a radio/TV station (31).

The olfactory bulb works much like a radio/TV station that listens in on their antenna signals (the ORCs) and receives, records, filters, modifies, edits and broadcasts a pulse basis bring in to the indoor environment as fruit, shampoo, dry cleaned clothes, perfume, glue and personal belongings (9). Our severe conclusion can be that we have a lot of “raw material” for chemical reactions indoors. Chemicals in soil water are indicators on that.

¤ ***favourable indoor air conditions*** are important from two aspects. First of all it gives the humidity, temperature gradients and vortex flows (10) that stimulates gas reactions, the mixing conditions and necessary transfer of “raw material”. Secondly the indoor air conditions would stimulate exposure from emissions if there are passive airflows that creates several transportation lines to the nose. Active ventilation systems and fans in vacuum cleaners, computers and other electrical equipment are other sources for air streams and also for transformation of chemical compounds, like ozone from copymachines.

A high dampness rate increases the likelihood of surface reactions because aerosols have a large surface-area-to-volume ratio and water is also a soluble for a lot of VOC. Gases like ozone (1 1), NOx and sulfurdioxid can stimulate reactions(9,12). They can enter via ventilation air and mix with the indoor air (6).

If we want to confine our analyses about interactions from VOC in the indoor air it is of great importance to separate VOC emissions and exposure of VOC. As an example we can consider the VOC benzene which is a carcinogenic. Sources for benzene emissions in the USA originate to 82 % from automobile exhaust, compared to individual activities 3% and tobacco smoke 0.1% (6). But when you look at exposure, automobile exhaust is only 18 % compered to individual activities 34 % and tobacco smoke 45 % (6) .

That means that VOC molecules will be VOC emissions through processes depending of building physics and than transformed to VOC exposure through chemical reactions and a VOC intake when it reaches the human body receptors. Controlled measurements can be done concerning exposure in reaction chambers.

Indoor air conditions can be decisive for gas reactions to occur. It can be compared with the conditions in a reaction chamber. There is a need for input systems, circumstances that supports molecular meetings and output systems that distribute the resulting compounds out from the reaction environment and in to the nose.

¤ energy will stimulate chemical reactions. One important energy source is free convection heat transfer from radiator surfaces to the surrounding indoor air (13). The energy transfer due to radiation, heat conduction and air movements close to a surface is fundamental knowledge in building physics and gives us an established theoretical background for calculations of energies necessary for chemical gas reactions in a simulated reaction chamber.

Electric coil surface radiators can have surface temperatures outside exceeding +90°C inner coil surface temperatures exceeding +200°C (2000 W radiator) under production of a continuous +70°C airflow. Continuous free convection heat transfer in the interval +60°C to +200°C from different kinds of electrical heaters, lamps and other sources means that we have enough energy for very advanced chemical gas reactions to take place.

Olfactory perception requires that the involved indoor air molecules have certain specific characteristics. Reaction products must fulfil certain demands concerning the surface structure of the molecules to be able to efficiently interact with sensors in the nose.

Its not possible to give a complete list of chemical characteristics that would be harmful for the individual, but certain groups of chemicals has been proven to interact as odours.

Among these groups we can point out four that interacts with man. Substances that are characterized as aromatics, short fatty acids, terpenoids and camphor (21).

frequency modulated electric magnetic field signal (18), primarily through fixed lines (19) to a certain number of receiver stations out in the neighbourhood (stations in the brain).

The information programs that will be sent from the olfactory bulb to different parts of the brain, are trigged off by the VOC molecules in the nose. The programs takes in to account a lot more information than just the molecular image. This information programs wiii contain all the iatest information that the brain need to take proper action, due to changes in the indoor environment.

The information program is transmitted first of all to thalamus which is the brains central command, which control all the outside environmental input to the brain, but the signals from the olfactory bulb is an exception because the bulb can also transmit to three other important secondary control centres of the brain, without passing thalamus, which is very unusual.

Since this paper tries to show some of the implications that signals originated from VOC molecules can lead to, its important to follow the olfactory information to the receiver stations and see what happens with the information presented.

The olfactory message of VOC is transmitted ***to aii four centres*** as foilows:

- ***the thalamus*** which is the brains central command that processes and distributes almost all sensory and motor information going to the cerebral cortex (15).
- ***the pyriform*** cortex control centre; the main olfactory discrimination region where sensory signals are distributed to other centres (20)
- ***the amygdala*** control centre; exercises a major control over the endocrine system, in particular hormones from *hypothalamus* and emotional expression (20).
- ***the hippocampus*** control centre; responsible for storing short term memories and preparing for long term storage (21).

We can foilow the chemical image pattern that was produced by the original VOC molecule aii the way to the ends and outputs of the human olfactory system.

A hypothetical VOC molecule can through the human olfactory system, that can percept this molecules, implicate: a release of hormones, influence emotional expressions and induce memory changes in the brain, among other things. The code for the original chemical image patterns from different VOC molecules are unknown but there are several theoretical models that could be of use for further scientific investigations.

4. Theoretical models for perception of VOC in humans

To percept a VOC molecule means that the olfactory bulb has to respond to the message of that molecule and also to commands from the central brain. The message in the molecular image depends on the functional groups of the molecule, Several theories tries to explain how the molecular image is read and coded by the receptors.

Molecule/Receptor Resonance Theory (21)	Thermodynamic Activity Theory (21)
Chromatographic Theory (21)	Membrane Penetration Theory (2 1)
Stereochemical Theory of Olfaction (21)	Immunochemical Theory (21)
Hansch Parameter Theory (21)	Molecule Image Analyses (1)

The VOC molecules active domain must in some way react with a receptor protein .

There are at least 1000 different olfactory receptor proteins, each encoded by a gene of their own. Smell can be blends of molecules. That means that the possible combinations are numerous. It is estimated that we can distinguish between 5000 different odourants and that we can detect considerably more (16).

There is also a possibility that the signal would interfere with the endocrine system, because there are interconnections between the central nervous system, the endocrine system and the immune system (22,23,30).

Even though that hormones are signal molecules in an internal signal system of the body and would be transported in the blood vessels, this process is still controlled from amygdala. It is also possible for amygdala to get signals through the nervous system (15).

That means that the implications on hormones concerning the perception of VOC would be that central parts of the command centre in the brain could get neuron signals from VOC perception, at the same time as it reaches feedback from the hormone system. Its not clear which signal that would dominate the following reactions but there is great need of research in this matter because this type of signal interference and disturbing interaction would be a primary effect of interaction between man and VOC in the indoor environment.

5. A sequential theoretical study of possible VOC effects on humans

We have seen that VOC compounds can be detected by the human olfactory system and cause an effect on the body. There is an acceptance that this can cause the sick building syndrome (SBS), in combination with poor ventilation (24,25). There is also an established increased risk for asthma in damp buildings with newly painted indoor surfaces (11, 25).

The intention of the following paragraph is to present a sequential theoretical study , a chain of events, just as a creative model and as an indicator of one possible process pattern that shows the interaction between building and man. This process pattern is not proven in any clinical study but might give us some clues of which kind of VOC effect we can expect from interaction through the olfactory system and how its possible to plan a study.

¤ a person is working in an office room near a corridor with newly painted walls and new carpets, in the end of the corridor is a special room for smokers.
¤ the paint and the carpets has been there since 6 months and there is no smell , TVOC measurements shows that there is TVOC concentrations, formaldehyde and benzene present in the indoor air but much lower than the established limits (8, 26, 27).
¤ the paint still fumes low emissions of DEHP and some unidentified VOC (8).
¤ the ventilation system is not working properly because air from the corridor goes in to the office room under the door and transports in to a warm radiator stream along the wall and the window. The air flow rate is bad because of bad maintenance. NO_x and ozone from cars in the street is present in the ventilation air.
¤ the corridor and office floor has been cleaned with causticsoda that has leaked in under the carpets and reacted with the formaldehyde emissions in the floor plates. Formic acid is produced (28) and it follows the airstream together with the other emissions into the office room.
¤ the radiator surface heats the gas molecules and a reaction starts that produces new VOC molecules with a characteristic planar form and an aldehyde group (12).
¤ when the heated airstream passes the window surface the gas molecules dissolves in the aerosol from humidity and transports to the persons nose (10, 12).

¤ the olfactory system in the nose detects the extremely low concentration of formic acid because it is an alarm pheromone and also the blend of VOC molecules and transmits the molecular images of the molecules to the olfactory bulb that compares this new signal pattern with information from the olfactory memory (1, 20, 29).
¤ the molecule image pattern mimics signal molecules that means that a serious (in an evolutionary sense) dangerous situation is coming up outside the body. The brain is fooled, because it is not used to this chemicals in the indoor air environment.
¤ all this actionsignals are sent to amygdala that trigg a lot of hormone activities in the body which react as in a stress situation (30).
¤ the person in the office room feels sick and the eyes starts to run.
¤ this procedure repeats it self every morning an, the building is classified " sick building"
¤ the person in the office would be sensitized against the particular VOC combination and each time the molecule image occurs, the olfactory memory sends out the same defence action program to the body.
¤ the allergic reaction later develops to an asthmatic syndrome.

This situation have never been proven, but we can study the possibilities for each step to occur in reality. There is a lot to reflect on in an interdisciplinary way. To be certain of that this scenario is possible to communicate to concerned disciplines, there is a need of a language of VOC, that can describe it. The purpose of the described scenario was to stimulate a discussion in a new context to learn more about VOC interactions and signals.

6. The signal process approach to VOC interactions

The main part of the olfactory system belongs to the brain which uses electro chemical signal patterns (19, 3 1) for daily process work. Treatment and transmission of chemical stimuli is standard procedure in the brain. A metaphor can be useful. If we take all trees in the amazon jungle (about 100 billions) and connect all leaves on the trees with each other by wiring (34), add that there are also possibilities for all trees to send signals to each other by radio transmission (3 1). Then you have an estimate of the complexity of the brains electrical signal system.

The brain is also a self organized system that adapt and changes the connections all the time as a response to outer and inner signals (3 1). The signal pattern is spatiotemporaled which means that the signals are distributed in space and time simultaneously (32). There is no established method to analyse all this electric signals at the same time but one tool that has been suggested is mathematical fractal theory (31).

A process of signal handling need information storage for new signals and there is in fact an olfactory memory (smell memory) that is located in the olfactory cortex of the brain which has connections to other parts of the memory in the brain (2, 21. 33).

An original perception and registration of VOC molecules in the olfactory memory can release picture memories the next time this VOC reaches the nose, which points to a connection with other parts of the brain (20). The brain is an excellent instrument to handle electrochemical input with, but its as good as its inputs. If the input is a new signal or an old recognizable signal, different action takes place.

A possible way to understand the interaction and the effects of signal interference of chemical compounds on humans, can be summarized by the following hypothesis:

¤ ***VOC molecules are chemical signals*** in the indoor air approaching the body
¤ ***VOC blends are signal patterns*** that involves information perceptible but ***misinterpreted by the bruin***
¤ Hormones and interlekuines are also chemical signals but they act in principles inside the body and act only on the command of the programmed and tuned brain.

The olfactory part of the brain pick up and translate this VOC signal patterns from the outside and transfer the information according to the program and tuning it is used to, since millions of years of interaction with the environment outside the body (1,20,29).

Since VOC molecules in an evolutionary way often are new man-made chemical signals, with active chemical domains similar to signal substances traditionally used by living organisms, the brain can be fooled and take improper action (1,20,29). It would misinterpret what is going on outside. The wrong action messages in form of neuron signals, hormones and interlekuines reaches different parts of the body ***and we feel sick.*** The body reacts with normal defence actions but towards the wrong signals. This signal approach can also give possible solutions to the increasing allergy and asthma rates and to SBS.

7. Conclusions

What are the conclusions from this VOC signal molecule journey and the signal process approach ? Would healthy buildings be constructed by fractal mathematicians and endocrinologists just to be sure that we can avoid SBS effects on man ? The answer to this is no. Skilled engineers and builders know how to construct and build high quality buildings, but it is not always possible to push this ideas through **because** of economical reasons.

However it is possible that the process of interaction and the answer to why people become ill from certain carpets or solvents in a composite building component, might be solved by fractal mathematicians.

In the meantime, dampness and sources to oxidation which supports chemical reactions, can be reduced. Interdisciplinary research can be done on signals and interaction between building and man. Investigations of houses where people are healthy can be performed. Increase the scientific communication and translate the results between the disciplines. Investigate, find and eliminate the worst well known chemical compounds ,

My hope with this paper is to stimulate an atmosphere of mutual respect between experienced builders, building engineers, physicians and theoretical scientists, within the frame of interdisciplinary cooperation .

References

1 . Hildebrand, J.G. (1995) *Analysis of Chemical Signals by Nervous Systems,* in Chemical Ecology, National Academy Press, Washington D.C. p 164-168

2. Ferencik, M. (1993) *Handbook of Immunochemistry,* Alfa Verlag, Chapman & Hall , London, p 33-35, 120

3. Griffin, J.E. and Ojeda, S.R. *(1996)Textbook of Endocrine Physiology,* Oxford University Press, New York, p 14.

4. Remick, D.G. and Freidland, J.S. (1997) *Cytokines,* Marcel Dekker, NY, p 357

5. *The Wingspread Consensus Statement,* in Colborn, T. et all.(1996) Our Stolen Future, Dutton, p 253

6. Wayne, R. 0. and Roberts, J.W. (1998) *Everyday Exposure to Toxic Pollutants,* Scientific American, Feb 1998, p 72-77
7. Berry, M.A. (1989),*Pilot study on indoor air quality,* CCMS report 183, (NATO/CCMS):5-26, ref. in Folkhalsoinstitutet rapport 1994: 16, p 38
8. Berge, B. (1988) *De siste syke* hus, Universitetsfijrlaget AS, Oslo, p 151-155
9. Weschler, C.J. *(1996) Chemical reactions among indoor pollutents as potential sources of irritants,* Allergistamma STH, presentation in session 4
10. Thibodeaux, L.J. (1996) *Environmental Chemodynamics,* John Wiley, NY, p 130
11. Barnes, J.P., Leff,A.R., Grunstein, M.M. and Woolcock, A.J. (1997) *Asthma,* Lippincott-Raven, Philadelphia, p 1170,1244.
12. Brimblecombe, P. (1986) *Air composition & chemistry,* Cambridge University press, Cambridge, p 55-64,75
13. Holman, J.P. (1997) *Heattransfer,* MC Graw-Hill, New York, p 337-345
14. Agosta, W.C.(1992) *Chemical Communication,* Scientific American Lib, p 113
15. Kandel, E.R., Schwartz, J.H. and Jessel,T.M. (1991) *Principles of Neural Science,* Appleton & Lange, East Norwalk, p 276-279,517
16. Levitan, I.B. and Kaaczmarek. L.K.(1997) *The Neuron,* Oxford University Press, New York, p 340-343
17. Stern, K. & McClintock, M. (1998) *Regulation of ovulation by human pheromones,* Nature vol 392, 12 mars 1998 p 177-179
18. Atkins, P.W. and Friedman, R.S. (1997) *Molecular Quantum Mechanics,* Oxford University Press, Oxford, p 365-367,397
19. Friesen, W.O.(1994) *NeuroDynamix Computer Models For Neurophysiology,* Oxford University Press, New York , p 103
20. Cohen, H.S. (1993) *Neuroscience **for** Rehabilitation,* Lippincott.,Phila, p 129-137
21. Martin, G. and Laffort, P. et.all (1994) *Odors and deodorization in the environment,* VCH publishers Inc., NY, p 11,20,148- 160,166.
22. Roitt, I.M., Brostoff, J. and Male, D.K., *Immunology,* Mosby, London, p 11.7
23. Geoffrey, M.C. (1997) *The Cell a Molecular Approach,* ASM, Wash. D.C.,p 521
24 Miller, *C.S.* (1996) *Chemical sensitivity: symptom, syndrome or mechanism **for** disease?* Toxicology 111, p 69-86
25 Norbäck, D. et all. (1996) *Asthma and sick building syndrome (SBS) in relation to building dampness and indoor painting,* Allergistamma, Stockholm, Abs 302
26 Bruner, F. (1993) *Gas Cromatographic Environmental Analysis*,VCH,NY,p71, 119
27. Carson,P.A. and Mumford,C.J. (1994) *Hazardous Chemicals Handbook,* Butter wort-Heinemann Ltd, Oxford, p 118
28. Lewis, R.J. (1997) *Hazardous Chemicals*,Van Nostrand Reinhold, New York, p 540
29. Hölldobler, B. and Wilson, E.O. (1990) *Communication,* the Ants, Harvard University Press, p 229
30. Male, D. et all. (1996) *Immunoregulation*, Advanced Immunology, p 11.13-16
31. Kelso, J.E.S. (1997) *Dynamic Patterns,* MIT press, Cambridge, Mass.,p 229-233
32. Calvin, W.H. (1996) *The Cerbral Code,* MIT press, Cambridge, p 15
33. Alberts, B. et.all (1994) *Molecular biology **of** the* cell, Garland, NY, p 758
34. Greenfield, *S.* (1997) *The human brain,* Weidenfeld & Nicolson, London, p 79
35. Kahle,W.(1993) *Nervous Systems and Sensory Organs,* Thieme,Stuttgart,p 210-215
36. Turner, R.J. (1994) *Immunology a Comparative Approach,* John Wiley, NY, p 11

Computer-Based Performance Modelling Tools for Natural Ventilation

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Abstract

Natural ventilation provides an attractive energy-efficient and sustainable ventilation mechanism following the emerging political and community pressures for Ecologically Sustainable Development. Performance modelling for natural ventilation is the first step towards its reliable control and design, which is critical for a much wider recognition and applications. Such performance evaluation and design tools are required by consulting and services engineers, building designers and architects.

The purpose of this paper is to outline the new design tools becoming available for the development of improved natural ventilation and energy saving strategies and how they are being applied to a variety of realistic projects.

The paper first reviews the natural ventilation technology and associated design issues in terms of flow pattern and ventilation flow rate. There are two basic air flow patterns in naturally ventilated buildings. Computer-based design tools such as analytical methods, multi-zone approaches (e.g. CHEETAH/MIX2.0), and computational fluid dynamics methods (e.g. VentAir) are described with different levels of design requirements and complexity of the design.

In partnership with Australian industry, the tools described in this paper is being applied on (innovative) ventilation projects, prediction of building thermal and ventilation performance at the design stage, analysis of indoor air quality, innovative ventilation schemes etc. The application of these modelling tools for three Australian building projects including an one-zone enclosure with natural ventilation, a multi-zone enclosure with natural ventilation and a multi-zone enclosure with mixed-mode ventilation, is described.

It is concluded that energy and ventilation design tools are improving, and becoming more readily available to the building and building services designer. As improved ventilation and energy strategies become available, they are playing an important role in ecologically sustainable development for building applications. Careful engineering design analysis has proven to be a cost-effective means of avoiding many building energy and ventilation problems. Application of these design tools has proven to be particularly effective for difficult or highly innovative building projects.

Keywords: Natural ventilation, design tool, modelling, application, flow pattern

1. Introduction

The emerging political and community pressures for Ecologically Sustainable Development will drive the need for more energy efficient buildings and improved building heating, cooling and ventilation strategies. Natural ventilation has been one of the technologies being considered, although quite often its effectiveness can only be achieved when used together with passive cooling and controlled properly. In some cases, supplementary mechanical ventilation systems are required and the ventilation system is said to be functioning in a mixed- or hybrid mode. Computer based design tools can play an important role in optimising design of natural ventilation to achieve the required energy savings and ventilation effectiveness. These tools range from simple programs based on analytical solutions, multi-zone numerical programs to much more computer-power-demanding computational fluid dynamics software,

New generations of energy and ventilation design tools provide faster and therefore cheaper analyses at the design stage, added confidence in system performance, and the opportunity to improve the design rather than fix the problem after construction. These design tool advances are primarily of interest in difficult natural ventilation problems - large building spaces, tall spaces, high heat loads, semi-enclosed spaces, partly air-conditioned, innovative building designs, some tunnels etc. Sophisticated analyses are usually not required for straightforward building projects which are currently being dealt with using existing design practices.

The purpose of this paper is to outline the new design tools becoming available for the development of improved natural ventilation and energy saving strategies and how they are being applied to a variety of realistic projects.

2. Natural Ventilation

2.1 Why Ventilate Naturally?

The question should really be asked is that if natural ventilation works, why ventilate mechanically. Natural ventilation is an old technology and can be found in many ancient cultures. Natural ventilation is also a clean, energy-efficient, and environmentally-friendly technology. However, its function is dictated by outdoor climate and building use in most situations, which means that the system might not provide a suitable thermally comfortable environment and might not provide sufficient ventilation at extreme conditions. This is partly due to the governing mechanism of natural ventilation and the uncontrollable outdoor climate, but it is also important to realise that many old and conventional designs were based on experience, rather than scientific approaches.

In Australia, the vagaries of weather make it difficult to predict or guarantee natural ventilation performance, and this alone will preclude the use of natural ventilation for many commercial buildings requiring guaranteed levels tightly specified thermal performance. However, the temperate weather conditions over many parts of Australia make natural ventilation an attractive option for many built environment applications, particularly where large building spaces are involved. For many building applications, mechanical ventilation systems are often impractical, or financially unattractive. For these applications, natural ventilation can provide good ventilation performance with low installation costs, no operating or maintenance costs, and operational reliability. The benefits from natural ventilation are now being recognised and it is being applied in many commercial and industrial applications.

Knowledge of fluid mechanics, turbulence and heat transfer has improved our understanding of natural ventilation. In the last twenty years, there have been some excellent efforts to develop simple design tools for natural ventilation. In recent years, more complicated tools have also been developed for determining ventilation flow rate and ventilation flow pattern. In particular, there have been a number of international joint efforts to develop design tools.

Engineering knowledge in natural ventilation design has also been enriched. This can be shown by a large number of innovative designs, for example, [1,2]. It is now possible to simulate quantitatively the natural ventilation performance before the system is built. Effective measurement techniques such as computer-based measurement systems and tracer gas methods are available for post-construction performance monitoring.

Above all, it is the emerging political and community pressures for Ecologically Sustainable Development that will drive the increasing use of natural ventilation, as pointed out in the introduction.

2.2 Mixing Ventilation Flow Pattern

Before describing performance-based design tools, it is necessary to revisit two basic flow patterns in naturally ventilated buildings. The mixing ventilation flow pattern generally occurs in buildings where wind-induced natural ventilation dominates. The wind-induced flow enters the building, interacts with the thermal plumes above the heat sources and other flow currents, and forms large recirculation cells. This flow is essentially similar to that found in a fully-mixed mechanical system as used in most building applications. This flow pattern mixes the incoming outdoor air with the room air and provides uniform temperatures and pollutant concentrations throughout the room. A cross natural ventilation system can generally provide such a flow pattern.

This flow pattern is generally easy to consider in a simulation program. In fact, most existing thermal performance and multi-zone ventilation programs assume that air temperature in each zone is uniform. However, wind-induced ventilation is also very difficult to simulate, due to the fundamental difficulties in predicting wind-induced flows around buildings. Mixing natural ventilation flow pattern is not common in commercial and residential buildings, but very common in some industrial and agricultural buildings. This flow pattern is certainly dictated by wind conditions.

2.3 Displacement Ventilation Flow Pattern

This flow pattern is generally associated with thermo-buoyancy-induced natural ventilation. The system introduces cool fresh air at floor level. Internal heat sources within the room warm the air which rises and stratifies. The heated air pushes the room pollutants upwards which are then exhausted to the atmosphere. This is a natural stratification process, providing fresh cool air at floor level, and mixed warmer air at the ceiling. The height of the interface between the fresh and polluted air is determined by the air flow rate, which is in turn determined by the thermal buoyancy force.

In buildings with a displacement ventilation flow pattern, there is generally a vertical temperature gradient. Surface radiation heat transfer is also important. The modelling problem is how to predict thermal stratification and the effect of thermal stratification on heat transfer and ventilation.

In practical situations, the flow pattern is generally a mixture of the two basic flow patterns.

3. Examples of Design and Analysis Tools

We have attempted to address the need for reliable natural ventilation design tools through its development of analytical solutions, multi-zone modelling and CFD modelling.

3.1 Analytical Approaches

Natural ventilation is a process of both heat transfer and fluid mechanics. There are two categories of analytical solutions, those for when the indoor air temperature is known and those for when the indoor air temperature is not known.

A well-known example of the first category solution is that for a single-zone building with two unequal area openings separated vertically by a height. Recently, we have been able to derive a solution for multi-zone buildings where each zone has effectively two ventilation openings. These solutions can be applied in many realistic situations where the problem can be simplified. These solutions have been converted to a number of successful design guidelines see for example, [3, 4].

In the second category are solutions where thermal buoyancy works alone, the most well-known solution being the emptying filling-box model where a single-zone building is considered. In this model, the enclosure is divided into two temperature zones, the bottom zone with cold and dense outside air, and the top with warm and lighter air. This model has recently extended to an emptying air-filling box model in which the bottom zone air can be heated by the warmer floor, which is heated up by surface radiation from the even warmer ceiling surface. A similar analytical solution can be derived for multi-zone buildings where each zone has effectively two ventilation openings. All the walls and partitions have to be assumed to be adiabatic.

These analytical solutions can be used not only for design purposes, but also for evaluation of the zonal modelling approaches.

3.2 Zonal Modelling - CHEETAH/MIX2.0

Zone modelling programs assume certain areas (zones) of a building to be fully mixed or have a vertically linear temperature profile. These programs are computationally fast, and enable overall ventilation flows to be calculated, without any spatial information within each zone. The MIX1 .O (Multi-cell Infiltration and eXfiltration) program was first developed by Li and Peterson [5]. In MIX1.0, an erroneous interpretation of the physical meaning of the concept of internal pressure in each zone prevented the calculation of bi-directional flows between zones. Recently, we [6] developed a consistent pressured-based formulation for natural ventilation of single-zone and multi-zone buildings with multiple openings . The formulation is made easier to implement by introducing an auxiliary concept of external pressure, which allows us to present all the formulas in a generalised form. The formulation was implemented in MIX2.0 [7]. Multi-zone situations considered in MIX2.0 include vertically interconnected zones, and horizontally interconnected zones with the same or different heights.

In MIX2.0, the building geometry and ventilation openings between each zone and outdoors are specified, flow rates are calculated as a function of pressure difference across each opening, and a mass balance and iteration applied to calculate the absolute pressure in each zone and air flow rate between each zone. MIX2.0 program considers fully the bi-directional flows through all large openings. These bi-directional flows are common in large commercial and industrial buildings, and must be modelled reliably if natural ventilation flow rates are to be predicted with reliability.

In order to compute the natural ventilation air flow rates through buildings, ventilation programs like MIX2.0 need to know the indoor temperatures within each building zone in order to calculate the respective pressure differences. Indoor temperatures however are dependent on the ventilation rates. To overcome this conundrum, our thermal analysis programs CHEETAH and MIX have been integrated to simultaneously compute building thermal performance, energy use and natural ventilation performance. The result is a powerful building thermal analysis program. CHEETAH is a program developed at CSIRO to calculate heating and cooling energy requirements for buildings, including housing. CHEETAH's simulation engine was chosen by Australia's Commonwealth, State and Territory governments as the most appropriate program for a national home energy rating scheme [8].

3.3 CFD Modelling - VentAir

While zone modelling provides rapid computation of air flow rates, zone temperatures etc for buildings, the spatial variation of air speeds, temperatures, contaminant concentration, and other air quality parameters are not available from zone modelling. Computational Fluid Dynamics (CFD) is now being increasingly used for this purpose.

In a CFD method, the building is divided into a large number of small elements or sub-volumes. The conservation equations for mass, momentum and energy are applied or discretised in each element or sub-volume. The resulting system of the linear equations is solved to obtain velocity components, temperature, concentration and pressure at each grid point. Cooling or heating load programs with various levels of complexity can be used to provide thermal boundary conditions for CFD, while CFD can provide detailed information such as air temperature distribution and convective heat transfer rate at solid surfaces for a cooling or heat load program. A well-integrated program allows the prediction of detailed air flow pattern, ventilation flow rates and detailed air temperature distribution.

There are at least two possible approaches to study the interaction between indoor and outdoor thermal environments. First, the computational domain can be enlarged to include the outdoor region around a building. Second, the computational domain is limited to the indoor domain. We prefer to use a pressure boundary condition at all external openings, and the wind pressure can be included.

There are many commercially available CFD programs available for the solution of fluid flow problems . In CSIRO, our finite volume CFD program Ventair (e.g. [9,10]) has been used.

4. Case Studies

The above ventilation and energy saving strategies have recently been applied to a number of innovative building projects. In each case, computer analysis and design tools have enabled ventilation and energy performance to be predicted and optimised for the intended purpose of the building. Three representative applications of this research are included below.

4.1 A One-Zone Enclosure - Sydney Fruit Market

This was a straight forward project to assess the likely contaminant levels from truck exhausts if the loading bays at Sydney's Flemington Markets were covered with a roof, Figure 1. The consultants Sinclair Knight Merz needed to assess the distribution of exhaust gas contaminants under the covered area.

The loading area was modelled using both CHEETAH/MIX and VentAir. Exhaust emissions were modelled for **24** trucks with engines idling, and distributed throughout the loading area. The distribution of exhaust gases was calculated for various design options in order to maximise the air quality. The design options included height of the roof, roof ventilator design and location, mechanical ventilation options, etc. The analysis showed the worst case scenario to be for no wind.

The adopted solution comprised a purely natural ventilation system with exhaust gases purged through roof ridge vents and the gap between the new roof and the existing buildings. The air change rates predicted by CHEETAH/MIX and Ventair agree well. A typical temperature distribution as computed from VentAir is also shown in Figure 1.

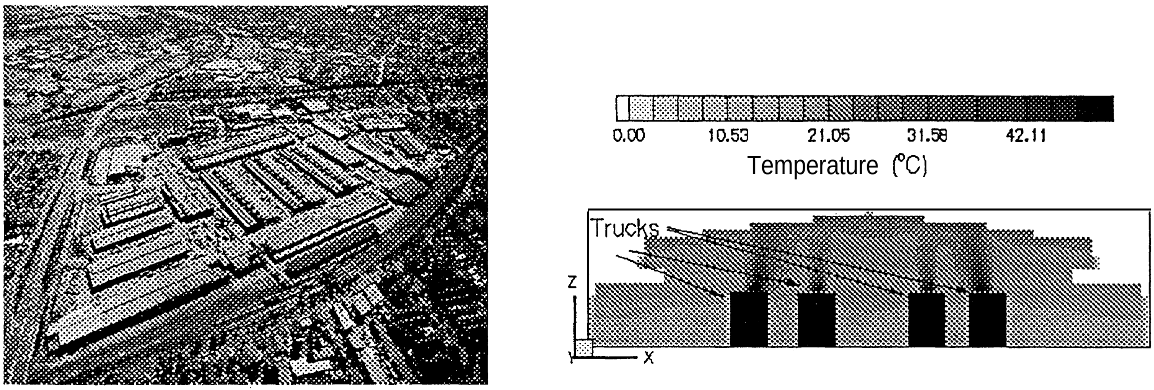

Figure 1: Sydney's Flemington Markets (left) and calculated air temperatures (right).

4.2 A Multi-Zone Enclosure - Copper Smelter

H H Robertson were engaged by Western Mining Corporation (WMC) to analyse the natural ventilation performance of a proposed copper smelter building to be constructed at Olympic Dam in South Australia. WMC had earlier experiences with excessively high operating temperatures in an existing smelter building at that site. The proposed building was geometrically complex and comprised multiple and interconnecting floor levels, with two main building areas, a casting building opening into the taller furnace building. The plant comprised several furnaces, molten metal launders, off-gas ductwork and many other heat sources. Total power dissipation into the building was about 13 MW. The emission of process gases required local ventilation systems in several strategic locations in the building. In this situation, natural or mechanically forced ventilation are the only cost effective methods of minimising the indoor air temperatures. The main concern was to minimise the indoor air temperatures in summer for the plant operators, under conditions where outside ambient temperatures can exceed 42°C.

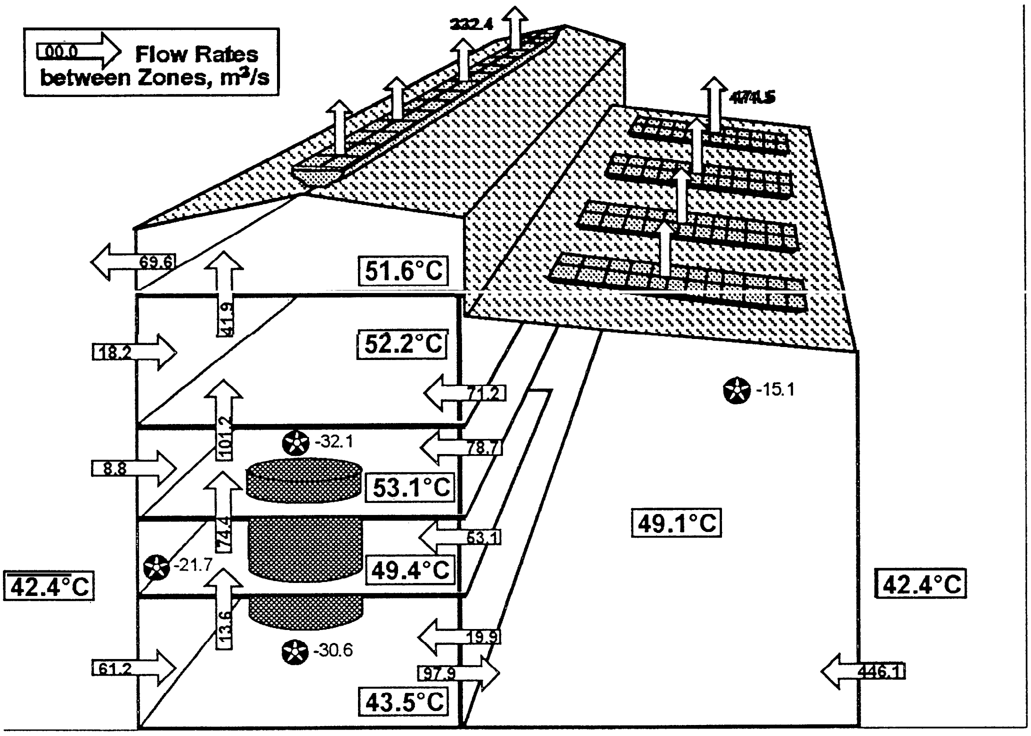

Figure 2: CHEETAH/MIX results for the Copper Smelter.

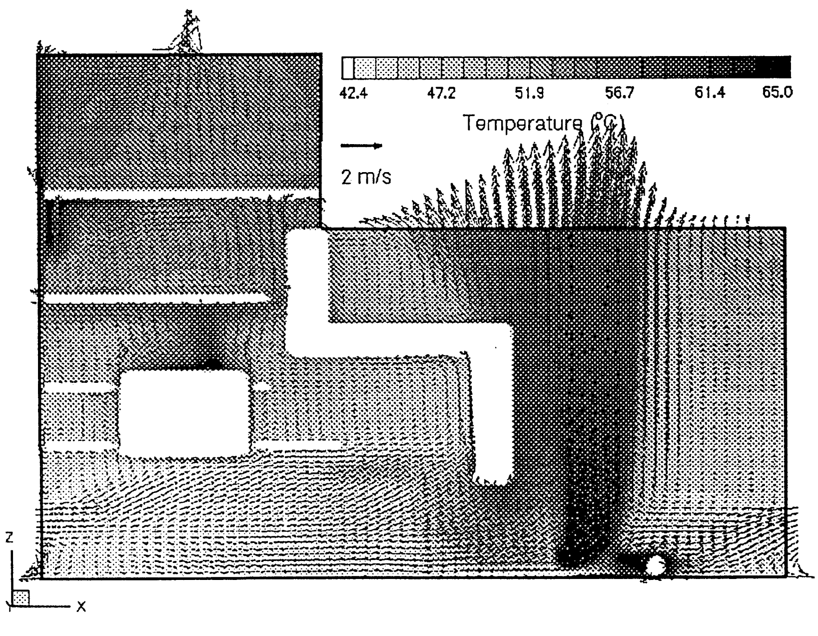

Figure 3: VentAir Calculation of Smelter Air Temperatures and Velocity for one vertical plane.

The first stage of the analysis involved CHEETAH/MIX to calculate the building envelope performance, indoor air temperatures, infiltration, exfiltration and air flow rates between all openings in all zones. Many design options were compared in order to minimise the building construction costs, and still achieve the required indoor operating conditions. Figure 2 shows the results of the zone modelling for one design case. The final solution was achieved using a purely natural ventilation system.

The second stage of the analysis involved a computational fluid dynamics analysis of the entire smelter building to determine the local temperature and air flow velocity variations. The analysis involved 500 000 grid points in VentAir. Figure 3 show one vertical section through the building from this VentAir analysis.

4.3 Mixed-Mode Ventilation - Manly Hydraulics Laboratory

This building includes a number of open floor plan laboratory and administration spaces, in a series of stepped areas down the sloping site. The NSW Dept of Public Works and Services has proposed a very innovative building design which is intended to provide summer cooling by natural ventilation. The building incorporates a plenum under each floor level. The plenums communicate with the occupied space above via air registers. Solar chimneys are added to distribute the exhausted air flow uniformly over the length of the building, and enhance the air flow rate through the entire system. Fans are installed to supply air to the plenums at night to provide night cooling when necessary. A schematic of the building concept with the envisaged air flow distribution is included as Figure 6.

The program CHEETAH/MIX were used to determine the thermal and ventilation performance of the building which was divided into 27 zones for the analyses. The analyses showed a number of unexpected ventilation flow rates and air flow patterns. The key problems to be overcome were the need to maximise the natural ventilation flow rates in order to provide sufficient cooling to the building, and to maintain a uniform upward air flow through the plenums to the rooms and out through the solar chimneys. It was found that in certain circumstances, air could flow down the lower solar chimneys, through the building and out through higher chimneys. Prior to the availability of programs such as CHEETAH and MIX, it would not have been possible to predict these abnormal flows, and therefore be able to minimise the problems at the design stage. The modelling work allowed us to advise on air flow control strategies, cooling energy savings and improved design options.

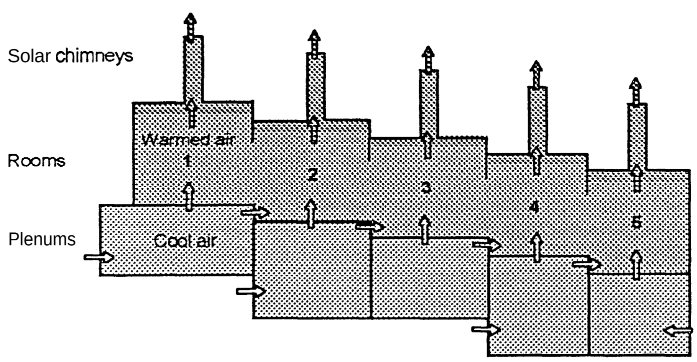

Figure 6: Schematic of the Manly Hydraulics Laboratory.

5. Conclusions

There is increasing interest in natural ventilation as an energy saving alternative to building heating, cooling and pollutant removal. Energy and ventilation design tools are improving, and becoming more readily available to the building and building services designer. They are playing an important role in ecologically sustainable development for building applications. Careful -engineering design analysis has proven cost-effective means of avoiding many building energy and ventilation problems. The computer-based performance tools have been used in the development of new energy and ventilation technologies. Application of these tools has proven to be particularly effective for the difficult or highly innovative building project.

6. Acknowledgment

The authors would like to thank H. H. Robertson, Sinclair Knight Merz and NSW Department of Public Works and Services for their permission to publish some of the results in this paper.

7. References

1. CIBSE (1997) Natural ventilation in non-domestic buildings. Application Manual AM10, UK.
2. Oppenheim, D. J. (1997) Natural ventilation. In Proceedings of 1997 ESD Conference in Architecture and Buildings. 27-28 October, Melbourne.
3. CIBSE (1988) CIBSE Guide, air Infiltration and natural ventilation, Section A4, Vol A, Design Data, UK.
4. BS5925 (1991), Code of practice for ventilation principles and designing for natural ventilation, British Standard.
5. Li, Y. and Peterson, P. (1990) The modelling of multi-room airflow and its application to exhaust ventilation analysis. Climate and Buildings. KYH, no.2, p. 15-28.
6. Li, Y. (1998) Prediction of natural ventilation in buildings with large openings, 1 - Basic formulations. Submitted to Building and Environment.
7. Li, Y., Delsante, A. and Symons, J. G. (1998) Prediction of natural ventilation in buildings with large openings, 2 - A computer implementation. Submitted to Building and Environment.
8. Delsante, A. E. (1997) The Development of an Hourly Thermal Simulation Program for Use in the Australian Nationwide House Energy Rating Scheme, CLIMA 2000 Conference, Brussels, 31 August - 2 September.
9. Li, Y. (1992) Simulation of flow and Heat Transfer in Ventilated Rooms, Royal Institute of Technology, PhD thesis, ISRN KTH/FR-92/18-SE, August.
10. Li, Y, Delsante, A. E. and Symons, J. G. (1997) Simulation Tools for Analysing Natural Ventilation of Large Enclosures with Large Openings, AIRAH Journal, no. 12.

Healthy and environmentally compatible building. materials, report on a German project

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Abstract
"Healthy and environmentally compatible building materials" is the title of a joint German four years project with a budget of DM 5 million. The Fraunhofer-Institute for Building Physics and the Institute for Toxicology and Environmental Hygiene at the Technical University of Munich are running the project. The purpose of the project is to promote the manufacture and widespread use of healthy and environmentally compatible building materials. Using the tools of chemistry, sensory evaluation and toxicology, the researchers develop evaluation criteria, measuring procedures and a data base for a wide diversity of product groups.
Keywords: Building materials of low emission, chemical measurements, sensory measurements, toxicological measurements

1 Introduction, aims of the project

For years producers and users of building products have been increasingly uncertain as regards the effect of these products to people's health and the environment. At the present time, a great skepticism even towards traditional and proved building materials can be observed. There is a lack of research and test results capable of overcoming or removing this uncertainty. A way out is supposed to be shown by the current joint project of the Fraunhofer-Institute for Building Physics (IBP) and the Institute for Toxicology and Environmental Hygiene at the Technical University of Munich (ITU), in close cooperation with industrial associations and companies. The project offers companies the possibility to provide themselves an additional competitive advantage as a result of the examination of their products (which will also be due to EC building product regulations). This advantage can be a achieved by pointing out the special features of their building products with respect to health and environmental compatibility.

The aims of the project are:

- The development, validation and testing of a standardized method for chemical, sensory and toxicological examinations of building products
- The use of scientifically approved and recognized standards and criteria for evaluation how healthy and environmentally compatible building materials are as well as for limitation of abuse by means of doubtful so-called building-biological examinations
- The active support of further development and introduction of Europe-wide standardized examination methods for this
- The establishment of a data base for documentation of the quality of building products, for supporting the planning of healthy and environmentally compatible buildings and for further developing the building products in cooperation with the European Data Base on Indoor Air Pollution Sources in Buildings [1].

2 Development of the chemical and sensory methods

Chemical and sensory matters are experimentally examined by IBP. In this respect, experiments with building products and building parts are carried out in a test chamber, with practice-oriented and building physical edge conditions being considered. Evaluation as regards quality and quantity of the substances emitted into the test chamber atmosphere is done by means of chemical analysis on the one hand and by the use of human olfactometric processes on the other hand.

2.1 Chemical methods

All over Europe, constructions of emission chambers are different. Differences are particularly obvious in the selection of materials, where two basic types can be observed: chambers made of refined steel and chambers made of glass. Our own tests using miniature chambers (50 ml - 30 1) have shown that especially with respect to the chemical fine analysis high material standards are to be defined so that even polar compounds can be proved in the chamber air with a satisfying re-detection rate. Electropolished refined steel has proved to be very advantageous.

The test chamber (with a volume of $1m^3$) used purely consists of electropolished refined steel to minimize wall effects and keep the re-detection rate at a high level. Furthermore, it can be thermically dosed. Defined settings and their tolerances can be seen in table 1. Apart from the classic $1m^3$ chamber type, which is chiefly used for the simulation of building physical parameters and installation situations (practice oriented conditions), IBP is already provided with several small-chamber systems. These are used for pre-experiments to define standards for larger emission chambers. For olfactory examinations a method has been developed which makes it possible to reproducibly measure odorous annoyances by means of test chamber examinations.

Table 1 Range of capacity for 1 m^3 emission chamber

Settings	range of capacity	range of tolerances
temperature	+10 °C bis +130 °C	±0,3 K by time ±0,5 K locally
change of temperature	cooling: ca. 0,3 K/min heating: ca. 0,4 K/min	not defined
relative humidity dew point	30 % R.H. to 95 % R.H. +5 °C to +88 °C	±1% locally ±3% by time
air velocity	0 to 0,5 m/s	±0,1 m/s locally and by time
desorption	230 °C to 260 °C at n= 5 h^{-1}	not defined
re-detection	> 80 %	not defined
air exchange	0, 0,1 to 2 h^{-1}	continously adjustable
chamber density	up to 1000 Pa compared to outdoor pressure	0,001 % of chamber volume per minute

During a first qualitative step high emission factors are intentionally generated under "worst-case conditions" like high temperatures, extreme loading of miniature emission chambers and no or a very low ventilation etc. These conditions which are not usual in practice lead to high concentrations of volatile and medium-volatile compounds in the chamber air, which facilitates identification of the compounds. In subsequent quantitative work steps the chamber air is, now under practice-oriented conditions, examined for the components found during the qualitative analysis. VOC's are concentrated on appropriate adsorbents and gas-chromatographically analyzed via thermodesorption. Aldehydes and ketons are collected via dinitrophenolhydrazine cartridges and quantified as a DNPH-derivate by means of liquid chromatography. Parallel to the quantitative analysis of single components the total emission is determined as a toluene equivalent.

2.1 Sensory methods

One of the aims of this package of tasks is the development of a method to find olfactory thresholds. In contrast to the commonly used method to detect odorous annoyances, comparatively reproducible test results are to be expected with this method. It requires the use of an olfactometer which allows low degrees of dilution.

With a good reproducibility this olfactometer can do with little sampling material and operates in accordance with the method of static gas dilution with the use of head-space bottles. As an odorless gas nitrogen or synthetic air is used. The head-space bottles serve as sampling and dilution containers at the same time. After the head-space bottle with the sample has been inserted into the olfactometer, the pressure within the head-space bottle is doubled and then released via a nose mask. This procedure is repeated until a test person does no longer smell anything. The value of the olfactory threshold is calculated from the weight of the sample or the volume of the head-space bottles and the number of extractions. The testing method can be extended by special sampling techniques. The head-space bottles can be evacuated, and samples can be taken from the emission chambers in situ. An operational test of the olfactometer lead to the results shown in table 2.

Table 2 Olfactory thresholds found by means of olfactometer, partially according to [2].

solvent	injected volume [µl]	concen-tration [mg/m³]	number of extractions	experi-mental threshold value [mg/m³]	olfactory threshold values in literature [3] [mg/m³]
Toluol	05 3	4360	8	17	0,6 to 153
Ethylacetat	10 3	9000	6	141	0,2 to 183
Ethanol (2 % Cyclohexan)	10	7900	6	123	
Ethanol	1,0	7900	3	988	19 to 672
Methylethylketon	1,0	8060	6	126	30 to 80
Isopropanol	10 3	7850	4	491	80 to 250
Fuel 80/1 10	10 ,	7160	4	448	3300
Xylol	05 ,	4325	10	4	1 to 100
Isopropylacetat	10 ,	8700	7	68	140
Methanol	10 ,	7900	2	1975	6,6 to 7800
n-Propanol	10 ,	8035	9	16	30 to 250
n-Butanol	10 ,	8100	14	05 3	0,36 to 77
n-Butylacetat	10 3	8820	11	4	0,35 to 48
Methylacetat	1,0	9270	4	579	145 to 550
Aceton	0,5 / 1,1	100 / 210	2 / 1	31 / 46	0,93 to 1862

In order to ensure testing methods to be practice oriented from a building physical point of view, the following parameters have been defined as testing and measuring factors:

- temperature
- relative humidity of the air

- surface specific ventilation rate
- flow velocity
- time of measuring

The interpretation of these parameters to a particular situation of measuring must include the respective inside and installation situation of a building product. With regard to -present norms and particular room climatic examinations the above parameters have been determined for initial tests in accordance with table **3.** The flow rate, which determines the surface specific ventilation rate, should not vary by more than ± 3 %. TVOC concentration should not exceed a value of **10** µg/m³ in the supply air (TÄ = toluolequivalent) or be below 2 µg/m³ for individual components. Some of the results are given by means of emission factors (EF). To this end, the average of two parallelly measured VOC concentrations is calculated:

$$EF = C_x (n/L)$$

EF = emission factor µg/[m2h]
C_x = chamber concentration of VOC,, µg/m³
n = ventilation in the chamber, h^{-1}
L = loading factor, m^2/m^3

The chemical analysis of volatile compounds from the atmosphere of the emission chamber is divided up into a qualitative and a quantitative step.

Table 3 Edge conditions for first emission tests.

test parameters	sample conditioning	emission measurement
temperature	**23** °C ± 0,2 K	**23** °C ± 0,5 K
air humidity	50 % ± 5 %	50 % ± 5 %
surface specific ventilation rate	**1** $(m^2h)^{-1}$	**1** $(m^2h)^{-1}$
air velocity	0,1 **to** 0,3 m/s	0,1 **-** 0,3 m/s

3 Development of the toxicological method

This part of the project is handled by the Institute for Toxicology and Environmental Hygiene at the Technical University of Munich (ITU). In this respect, the toxic potential of building materials is estimated by means of literary data on the one hand, which is due to their chemical compositions and the emissions/immissions to be expected. On the other hand, the toxicity and eco-toxicity of building products is tried to be defined directly via their emissions/immissions by means of biological in-vitro testing systems. Another approach is the comparing toxicological evaluation of immission samples taken from typical houses (pre-fabricated houses, wooden houses, houses with gas heating, open fire-places and others).

4. References

1. Molina, I.L. et al. (1996) European Data Base on Indoor Air Pollution Sources in Buildings: current status of data base structure and software, INDOOR AIR '96, Vol. 3, pp. 531-536

2. LABC-Labortechnik (Hrsg.): LABC-Olfaktometer - Zur Bestimmung der Geruchs-intensität. LABC-Labortechnik, Hennef (1996).

3. Devos et al: Standardized Human Olfactory Thresholds. IRL Press at Oxford University Press (1990)

Assessment of energy conservation measures suitable for retrofitting residential buildings in Kuwait

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Abstract
The code of practice for energy conservation in buildings was enforced by the Kuwaiti government through the Ministry of Electricity and Water in 1983. This implies that the most buildings built prior to the enforcement of the code lack the measures required to achieve efficient usage of energy. Significant energy saving potential may be realised from such buildings if suitable retrofitting schemes were implemented.
This paper addresses a number of energy saving retrofitting schemes, which are considered suitable for old residential buildings in Kuwait. The energy conservation measures considered for retrofitting were considered with the building envelope including the application of thermal insulation and use of energy efficient windows. For each scheme, a building model was developed and interrogated using the DOE2.1E energy simulation program.
The workability of the different schemes was investigated with some considerations given to the benefits and limitations related to installation techniques (such as interior vs. Exterior fitting of insulation material). Moreover, a cost benefit analysis for each scheme was also conducted in terms of energy utilization and cost requirements coupled with an optimization analysis to determine the best retrofitting scheme.
Keywords: Energy Conservation, Exterior Insulation and Finish System, Retrofitting.

1 Introduction

Retrofitting involves making considerable changes to existing buildings. These changes aim to rectify existing damage, improve building standards and increase or modify the capabilities of a building use. The range of energy saving measures involving retrofitting of residential buildings is significant. Energy saving improvements can be made to the building envelope, the building services and the appliances within the building. These range from those designed to improve the thermal efficiency of the building envelope to those which minimize internal heat gains and achieve better control of heating, ventilating air-conditioning facilities. Energy efficient design in building has progressed significantly in recent years, allowing for older building component to be retrofitted with respect to energy. Although residential retrofitting usually cannot be justified solely from an energy perspective, incorporating energy efficient principles into an existing retrofitting scheme can save future energy costs and alleviate wasteful consumption of energy. In this study retrofitting of residential buildings in Kuwait is being analyzed.

In Kuwait the Ministry of Electricity and Water (MEW) issued an energy conservation code in 1983. This code represents a set of regulations that guide the construction of new buildings. All houses that were authorized to be built prior to the code did not include any energy conservation measures such as using insulating materials and efficient glazing systems. A sample building which is used as a base case for the study analysis represents a house that lack the use of energy conservation measures as it is was authorized to be built before the implementation of the code. The case study house was built by the National Housing Authority (NHA), as a medium income family house.

2 Methodology

For the case study, a base case (case 0) was defined to represent a reference point. This base case represents the building as it was constructed. The building did not include any insulation materials for the wall and the roof sections. Moreover the windows were made of a single clear glass.

By the use of the DOE-2.lE building simulation program, in which the base case was entered, the building energy consumption and the peak load were determined. After that 14 different cases were constructed to represent different retrofitting cases and entered in the DOE-2.lE program to estimate their energy consumption and peak load electrical power details.

The different retrofitting cases are listed in table 1. Each case involves a different effect of adding an energy efficient system. Some effects are single effects such as adding wall insulation only, or roof insulation only or changing the glazing system alone. Other cases involve double or triple effects, they represent a combination of the single effects (ex. addition of wall and roof insulation at the same time), thus increasing the percentage of energy savings. Case 15 includes wall and roof insulation as well as double reflective glass. Thus it is the same as case 5, but the window area was reduced.

Case #	Description
0	Base case (no insulation), Infiltration = 1 .O single clear glass
1	Wall & roof Insulation, single clear glazing
2	Wall insulation only
3	Roof insulation only
4	Wall & roof insulation, Clear double glass
5	Wall &roof insulation, Reflective double glass
6	No insulation, Clear double glass
7	No insulation, Reflective double glass
8	Wall only, Reflective double glass
9	Roof insulation only, Reflective double glass
10	Wall only, Clear double glass
11	Roof insulation only, Clear double glass
12	Wall &roof insulation, Reflective single glass
13	Wall insulation only increased R-value =15, Clear single glass
14	Roof insulation only increased R-value = 20, Clear single glass
15	Wall &roof insulation, Reflective double glass, Decreased window area

Table 1. Retrofitting cases description

3 Case study

The case study house is a two story building with an area of 27m x 19m. The living space area is $307m^2$. Walls and roof are not insulated. Windows are single glazed. For the retrofitting cases were insulation is used wall and roof insulation material was chosen to be extruded polystyrene as it is the most commonly used insulation material in Kuwaiti buildings [5].

4 Retrofit system installation

As it has been explained before, energy efficient retrofitting is concerned with improvements that can be made to the building envelope, the building services and the used appliances within the building.

In this study retrofitting measures that are related to the building envelope only were considered and they include adding wall, roof insulation and using an energy efficient glazing system.

From the theoretical point of view, buildings envelop energy efficient retrofitting can be obtained by applying several modifications to the wall, roof and glazing system. A combination of these modifications would lead to the optimum energy saving retrofitting case. But when it comes to implementation of the best retrofitting case other consideration will come into the picture, such as the fitting of the insulation materials.

Appropriate thermal insulant can be fixed on the external face of the building, internal surface of the wall of a room, or injected as foam, granules or fibres into any cavity within the wall. In Kuwait the wall structure does not include a cavity. Thus the fitting of thermal insulant, either on the room side of the inner leaf, or the weather-side of the outer leaf of the building are considered.

4.1 External insulation

It is the most suitable where the roof has a large overhang and the wall requires renovation and is composed of simple rectangular shapes with few fixings, such as pipes, which would have to be removed before the application of the insulant and refitted subsequently. Apart from the noise created during the fixing, there should be little disturbance to the occupants of the building during this retrofit operation.

Once the insulant is in place, the rate of heat loss is reduced and the fabric of the building acts as a better energy store, resulting in the occurrence of a more stable internal temperature. External cladding also reduces the temperature fluctuation (and hence mechanical stress generated) in the brick of the wall, and so less severe cracking is likely to ensue. Moreover, the external fitting of insulation would not affect the floor area. Unfortunately, the outer rendering, which protects the insulant from the vagaries of the weather, may also be susceptible to cracking so allowing rain, wind and atmospheric pollution to penetrate into the externally applied insulant, thereby reducing its effectiveness. [1].

4.2 Internal insulation

The installation of internal insulation occurs in some renovation projects, but it causes considerable disruption to the occupants of the building. Also, it normally requires additional differently skilled tradesmen to remove and/or resite the building services and ‘fixed’ furnishing (e.g. electricity sockets) mounted on, or sited near to, the affected walls. A further disadvantage is that the attachment of thermal insulant to the wall surfaces of room reduces the available floor area.

However, there are advantages in choosing to internally line the building with a thermal insulant. For instance, on multi-storey buildings is not required and the installation is not dependent upon good weather occurring, as would be needed for the application of insulation externally. Its presence is suited to the intermittent occupation of the building, because the room surfaces heat up quickly and are soon not ‘cold to the touch’. Also, most internal linings have significant sound-deadening qualities and can also provide excellent bases for surface finishes.

5 Building energy consumption analysis

From the results of the energy consumption data obtained by DOE-2.lE program and the analysis of the data table 2 was generated. By comparing the peak electrical load consumption to the base case, the optimum case was case 15 which involves the use of insulation for walls, roof and reflective double glass with reduced window area. The electrical load consumption was reduced by a value of 37.347 %.

The use of wall insulation only reduced the electrical load by 13 % while the use of roof insulation only reduced the electrical load by only 3 %. The effect of using a better glazing system reduced the electrical load by 7 % and 11 % for the double clear and double reflective glass respectively. By comparing cases 5 and 15 the window area reduction further dropped the electrical load by 6%.

Case No.	Peak Electrical KW	Peak Elec. Consumption W/m²	Annual Energy MWh	Annual Energy Consumption KWh/m²
0	36.70	119.529	148.958	485.2
1	29.85	97.225	108.302	352.8
2	31.89	103.863	119.575	389.5
3	35.55	115.814	137.43 1	447.7
4	27.13	88.382	99.460	324.0
5	25.15	81.917	86.059	280.3
6	34.21	111.423	139.866	455.6
7	32.61	106.222	126.744	412.8
8	26.76	87.152	97.339	317.1
9	29.55	96.254	115.181	375.2
10	29.17	95.019	110.672	360.5
11	32.84	106.969	128.367	418.1
12	28.58	93.107	96.863	315.5
13	31.45	102.446	117.300	382.1
14	35.36	115.166	136.254	443.8
15	22.99	74.889	73.18	238.4

Table 2. Total electrical requirements of the building

5.1 Peak load details

Figure 1 represents the peak load details of the building. It shows the breakdown of the total building cooling load when it reaches its maximum value (i.e. the peak cooling load). For case 15, which is the best energy efficient retrofitting case the main contributor to the building cooling load is the infiltration component (infiltration is the rate of uncontrolled air exchange through unintentional openings that occurs under given conditions), this component reduction would require use of weather strippers for windows and doors.

The heat gain by the different components of the building is shown in fig.1 shows the effect of using the wall insulation in different cases as compared to the base case. The wall gain dropped from 10.139 KW to 1.993 KW. And the effect of adding the roof insulation had dropped the roof gain from 4.238 KW to 0.82 KW. Further more, the use of a reflective double glass compared to the clear single in case 0 dropped the window gain from 6.235 KW to 4.024 KW. The reduction of window area decreased the window gain from 4.024 KW to 1.661 KW and increased the wall gain from 1.993 KW to 2.198 KW due to the increase of the wall area. The lowest annual electrical energy consumption was that of case 15.

5.2 Optimum energy consumption

The total annual energy consumption for the different cases is listed in table 2. The optimum case was case 15, as it’s annual energy consumption was found to be the

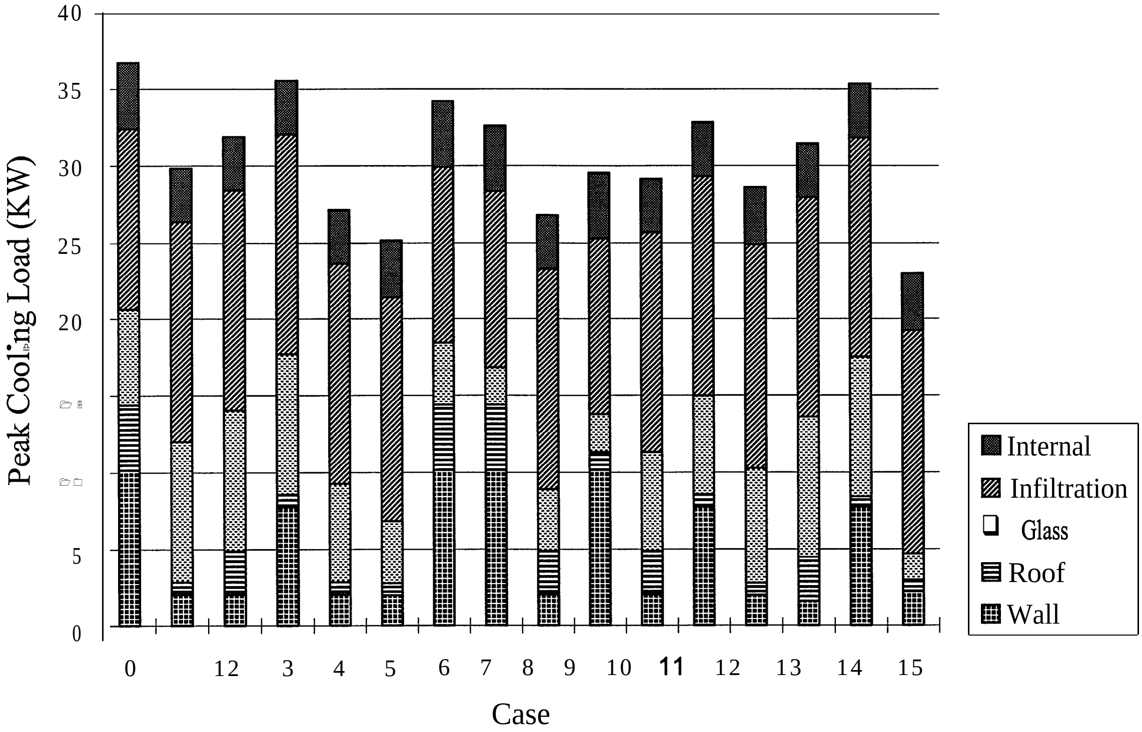

Fig. 1 Peak cooling load distribution for each case

minimum and of a value of 73.18 MWh compared to that of the base case which is 148.96MWh. Cases 13 and 14 were included to measure the single effect of increased R-value of wall and roof. Case 13 represented wall insulation only with R-l 5 resistance and case 14 represented roof insulation only with an R-20 resistance. Theses two cases were to be studied to provide an energy efficient retrofitting method if the building owner would like to change the wall exterior finish only or roof only. For case 13 the increased R-value further dropped the total annual electrical consumption by 1.6% in comparison to case 2 which represented the conventional recommended wall of R-l 0. For case 14 the increased R-value dropped the total annual electrical consumption by 0.76% in comparison to case 3 which represented the conventional recommended wall of R-1 5.

6 Cost benefit analysis

From the energy consumption analysis, the optimum case was case 15, the one that included all considered energy conservation measures with a reduced window area. Further analysis was carried out to determine the feasibility of the different retrofitting options. The customer investment for each retrofitting option was calculated. Particular assumptions were made in calculating the cost, as certain materials were used. For example, the new exterior finish of the building was assumed to be sand lime bricks.

The payback period for the customer was assumed to be 12 years, and the calculations were carried out accordingly. After 12 years the initial cost of retrofitting was not covered yet. The price of electricity for residential buildings is 2 fils/KWh (1 KD = 1000fils, 1 US$ = 0.306 KD), with that amount the payback period of the most expensive retrofitting options would be 51 years. As case study building was retrofitted thus the government will cover only the subsidised amount of electricity which is 32 fils/KWh. The payback period for the government will start from day one, as the government did not contribute to the initial cost of retrofitting and the electrical load for all the retrofitting cases was reduced. Table 3 shows the combined affect on the customer and the government, the national performance indices. Case 15, after 12 years shows the highest national performance index of 81.96 KD/m^2.

The number of residential buildings built prior to the application of energy saving code in Kuwait is over 42000. With that number, the total annual savings for the government for case 15 was found to be 100 million KD. For case 6 which was the case with the maximum annual consumption after the base case, total annual savings was found to be 12 million KD.

Case No.	Total Investment In Energy Conservation Measures	Annual Savings In Electric Energy Consumption	Total National Savings (12 years)	Normalized National Savings
	KD	KD	KD	KD/m^2
1	4107.0	1382.3	12480.65	4.5
2	1876.0	999.0	10112.26	3.3
3	2231.0	391.9	2472.02	1.3
4	6060.0	1682.9	14135.18	5.5
5	6438.0	2138.6	19224.79	7.0
6	1953.0	309.1	1756.54	1.0
7	2331.0	755.3	6732.3 1	2.5
8	4207.0	1755.0	16853.55	5.7
9	4562.0	1148.4	9219.02	3 7
10	3829.0	1301.7	11791.69	4';2
11	4184.0	700.1	4217.13	2.3
12	5808.0	1771.2	15446.76	5.8
13	2144.0	1076.4	10772.46	3.5
14	2328.0	43 1.9	2855.23	1.4
15	5754.0	2576.4	25162.61	8.4

Table 3. Overall performance indices

7 Conclusions

The best retrofitting alternative should work along with the renovation of the building. If the owner of the building is considering changing the building outer cladding, the external fitting of the wall insulation is recommended. If the window glazing is considered it is recommended to use a wall resistance of R-10 supplied by the energy conservation code. If the glazing system is not changed then an increase in the thermal resistance of the wall is recommended. In internal fitting of insulation material it is a advised to use safe insulation such as the fibre glass, as in case of fire it will not produce toxic vapours.

The optimum energy conservation case was found to be the one with a triple effect in which the glazing system was changed to double reflective, wall, roof insulation materials were added and the window area was reduced. By the use of the conservation measures the percentage of electrical load reduction reached 37.5%. In comparison to single effects the electrical load reduction ranged from 3% to 13% for wall and roof insulation respectively.

This study presented different retrofitting options along with their energy consumption analysis and their cost effectiveness. In real situations each retrofitting project should be studied individually to take care of the project needs. Once the needs and requirements of each project are determined the most appropriate and cost effective system option or application method can be selected from those that are available.

It was found that the ventilation component of the building load was the major contributor to the building load, but it was not considered in this study. Thus any effort to reduce this component would have a great impact in reducing the total load. One way of reducing this part of the load is by decreasing the amount of uncontrolled air leakage by applying weather strippers to doors and windows.

The retrofitting cases payback periods for the customer were over 30 years, which is very long. Therefore, the building owner must be encouraged to retrofit his building by offering initial cost subsidisation and restricting the renovation loan acceptance with a condition that the building owner must retrofit his building with the most suitable option for his building.

8 References

1. Adderly, A. E., Probert, S.D., and O'Callaghan, P.W. Materials and retro-fit methods for reducing rates of heat loss through walls. Applied Energy V. 35, nl, 1990, pl-11.

2. Annual statistical abstract. 1996. Ministry of Planning Central Statistical office. Edition 33. Kuwait.

3. Egan William F. 1995. Proceedings of the International Symposium on Exterior Insulation and Finish System (EIFS).

4. Energy Conservation Program, code of practice MEW/R-6, first edition 1983. Ministry of Electricity and Water. Kuwait.

5. H. Al-Mudhaf, E. Aasem, R. Murad, F. Alghimlas. 1997. Workmanship factor on the effectiveness of conservation measures. Kuwait Institute for scientific Research, Report No. KISR 5011, Kuwait.

6. Sam Cohen, Charles Goldman and Jeff Harris. Energy savings and economics of retrofitting single family buildings, Energy and Buildings, v. 17, n4, 1991. Page 297-311.

Energy and IAQ assessment of the Swedish housing stock

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Abstract

This paper presents assessments of energy efficiency and IAQ aspects of the Swedish housing stock based on sample survey data. The data consist of technical information about the housing stock, indoor climate measurements and information about the health of the residents. Also included in the database is a weighting system which makes it possible to estimate the characteristics of the housing stock and of any subgroups which are of interest to study.

To analyse these data, a computerized simulation model has been developed. The model can be used to assess the current state of the housing stock in terms of energy usage (space and water heating, ventilation, lights and appliances) and IAQ aspects. It can also be used to estimate the effects of and costs for measures to improve the housing stock with respect to energy efficiency and IAQ aspects.

The model contains a special function, kernel density estimation, by which plotted distributions of measured IAQ factors can be obtained. This function is used in the paper to assess the indoor air quality in the Swedish housing stock, by comparison of the distributions with prescribed norms and threshold limit values for measured indoor climate factors. A special study of ventilation is reported, where the consequences of increased ventilation, in terms of energy consumption and costs, are analysed.

Keywords: microanalytic simulation, density estimation, energy efficiency, indoor climate

1 Introduction

The paper describes two applications of a computer model for analysis of the Swedish housing stock with regard to energy efficiency and indoor climate.

The model is intended to be useful for studies of the balance between an efficient use of energy and a comfortable and healthy indoor climate, which is of vital importance for a sustainable development of the Swedish housing stock.

The first application is an assessment of the indoor air quality in the Swedish housing stock. The results indicate that an increase of the ventilation is required to safeguard a healthy indoor climate. The second application is a study of energy consequences of increased ventilation.

2 The ELIB survey

The ELIB survey, described in [1] and [2], was executed in 1992. This survey has a threefold purpose

(1) To obtain a technical description of the Swedish housing stock.
(2) To describe the indoor climate in the Swedish housing stock.
(3) To study potentials to save electricity in the Swedish housing stock.

Technical inspections and measurements of the indoor climate were performed in a sample of resedential buildings. Health symptoms and troubles were recorded by a postal questionnaire study.

When data for the buildings are analysed, the population is the Swedish housing stock, consisting of about 1.8 million buildings. When data from the postal questionnaire are analysed, the population is the 7.5 million residents of the Swedish housing stock. The original size of the building sample was 1200 and the number of investigated buildings was 1103, which means that non-response occurred in 8.1% of the ELIB sample of buildings.

3 The SIMBA model

The SIMBA model (Simulation Model for Building Analysis) has been developed for analysis of the Swedish housing stock with respect to energy efficiency, IAQ aspects and environmental impact.

The model is based on the principles of microanalytic simulation. This means that the model operates on the level of individual *microunits,* which for the SIMBA model are constituted by residential buildings. The properties of interest to study, for instance, energy use and indoor air quality in the housing stock, depends on technical characteristics, outdoor climate and habits of the residents of individual buildings. These dependencies are in the model expressed by mathematical and statistical relationships. In microsimulation modelling, such relationships are called *operating characteristics* of the microunits. A special heat balance model is contained in SIMBA for modelling of the operating characteristics that determine the energy consumption for heating a building. For a more detailed description of the model, see [3].

The data, required by the model, come from technical inspections of buildings and indoor climate measurements, performed in the ELIB sample survey. The model and its data can be considered as a miniature of the Swedish housing stock. This miniature can be scaled up to represent the whole housing stock, by a weighting system that is determined by the sampling design. This means that the model can answer questions such as:

What would be the total effects (in terms of energy consumption and costs) if the insulation is improved or if the ventilation is increased in all buildings in the Swedish housing stock ?

The uncertainty in the results, that depends on the randomness of the sample and random errors in data, can be determined statistically with variance estimation techniques.

4 IAQ assessment and description of energy use by density estimation

Measurements of indoor temperature [°C], ventilation air flow [m^3/h], relative air humidity [%] and radon gas concentration [Bq/m^3] were performed in each building of the ELIB sample survey. In addition, measurements of the concentration of volatile organic compounds (VOC) [µg/m^3] and formaldehyde [µg/m^3] were performed in a subsample of 100 single-family houses and 100 multi-family buildings.

Authorities which safeguard a good indoor climate in Swedish homes have prescribed requirements for a good indoor climate by the use of threshold limit values, norms and recommended levels for the IAQ factors. Such factors were measured in ELIB.

For some of these IAQ factors, ELIB provides for the first time ever, a possibility to assess the indoor air quality in the Swedish housing stock, by comparison of measurements from a nation-wide investigation with prescribed requirements.

Kernel density estimation is a method for estimation of probability distributions. This method provides an informative graphical tool for assessment of the indoor air quality, by diagrams in which values for prescribed indoor climate requirements are indicated in plots of estimated distributions for the measured IAQ factors.

A popular way to describe kernel density estimation is, that a 'bump' is placed on every observation and the estimated probability density function is obtained as the sum of the bumps. In the mathematical formula, the bumps are represented by a *kernel function* (K) and the formula for the kernel density estimator is given by:

$$\hat{f}(x) = (1/nh)\sum_{i=1}^{n} K[(x - X_i)/h]$$

where X_i are the measured observations, n is the number of observations and h is the 'bandwidth' or 'smoothing parameter'. Further details of this method are given in [4].

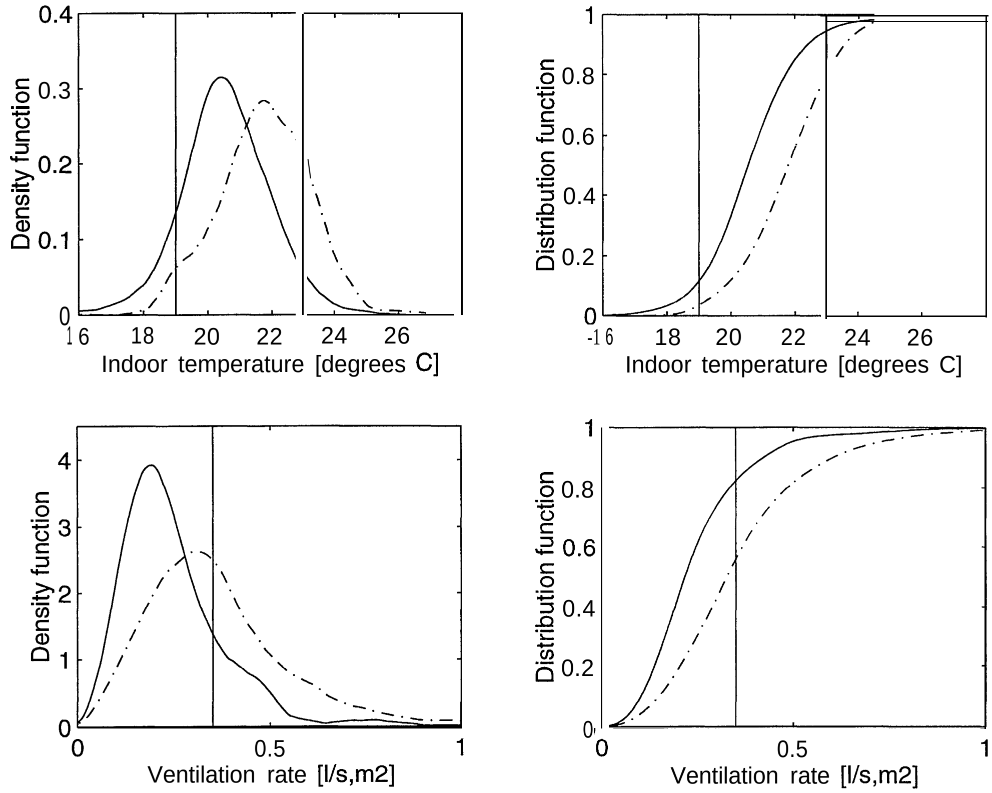
The given formula for the kernel density estimator is not directly applicable on data from a sample survey, where each observation has a weight (w_i) that reflects the relative importance of the observation. The SIMBA model contains a modified version of kernel density estimation, which is described in [5]. This density estimator is computed as:

$$\hat{f}(x) = (1/nh)\sum_{i=1}^{n} v_i K[(x - X_i)/h]$$

where v_i are equal to the survey weights (w_i) divided by their mean value $(\overline{w})$. By this standardization of the weights, the estimator will fulfil the requirement that its integral over the interval (-=, ∞) is equal to 1.

For the assessment of indoor air quality, estimated density functions are useful to show how the shape, location and spread of the distributions are related to prescribed recommendations, norms and threshold limit values. Estimates of the percentages of the Swedish housing that fulfil prescribed requirements, are more directly obtained from distribution functions than from density functions. Therefore, distribution functions are also estimated with the model, by numeric integration of estimated density functions. Some results of this application of the SIMBA model are presented in Figure 1 and Figure 2.

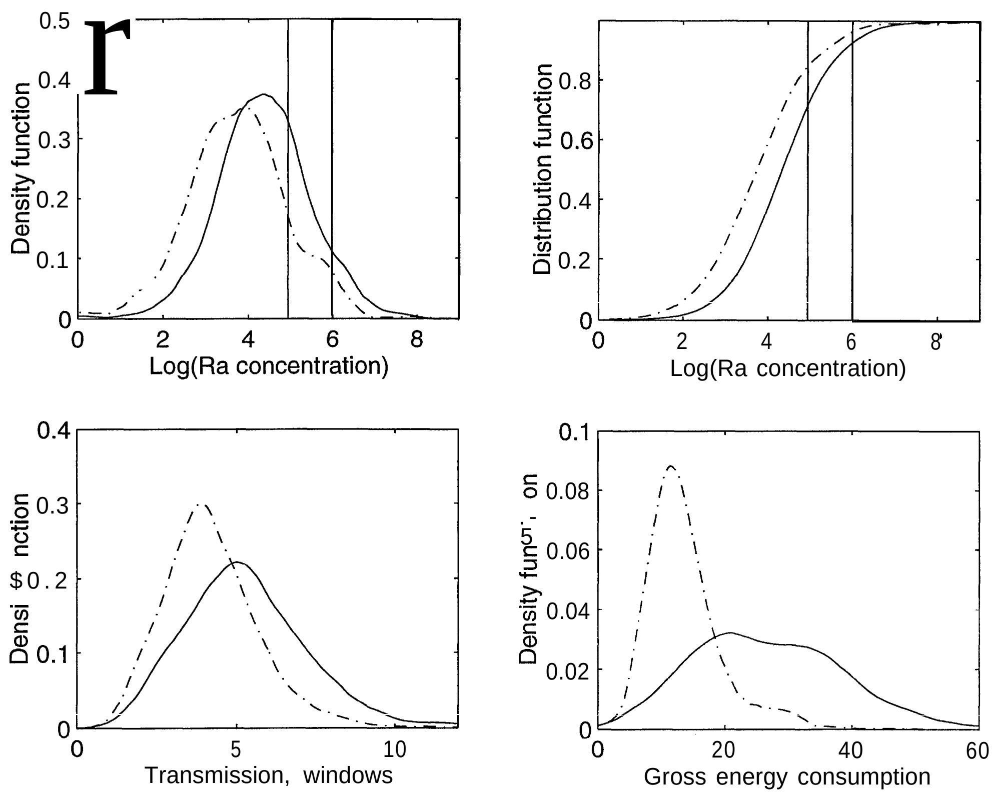
Figure 1. *Distributions of indoor temperature [° C] and ventilation rate [l/s,m^2] in single-family houses (solid curve) and multi-family buildings (dotted curve)*



The indoor temperature influences the energy consumption and is also important for the comfort of the residents. When the energy consumption is discussed, an indoor temperature of 20°C is often recommended. From comfort aspects, the 'directed operative temperature' is recommended to lie between 20°C and 24°C. The interval from 19°C to 23°C, indicated by vertical lines in the figure, is a compromise between these recommendations. According to the estimated density functions, a large proportion of the Swedish housing stock has an indoor temperature in this interval. Comfort problems from low temperature are most likely to occur in single-family houses. The estimated distribution function shows that about 10% have an indoor temperature below 19°C in single-family houses. Waste of energy due to unnecessary high temperature will mainly occur in multi-family buildings. About 20% of the apartments have an indoor temperature above 23°C.

For ventilation, there is a norm for new construction in Sweden. The ventilation rate should be at least 0.35 l/s,m^2 according to the norm. In the plotted distributions for ventilation, the norm value (0.35 l/s,m^2) is indicated by a vertical line. Estimated proportions, for which the ventilation norm is not fulfilled, are given by the intersections of the vertical line with the distribution function curves. These proportions are about 55% for multi-family buildings and over 80% for single-family houses. Thus, the ventilation is lower than the norm value in a substantial part of the Swedish housing stock, which is a rather surprising result.

Figure 2. *Distributions of radon gas concentration in natural log of [Bq/m^3] units, transmission through windows [MWh/apartment, year] and gross energy consumption [MWh/apartment, year]*



The upper part of Figure 2 shows estimated density and distribution functions for radon gas concentration. From a consideration of the risk for lung cancer, certain threshold limit values have been prescribed for the radon gas concentration in Swedish buildings. These values, which are 400 Bq/m^3 for older buildings and 140 Bq/m^3 for new construction, are indicated by vertical lines in the figure. Measures to decrease the radon concentration are most urgent in buildings where the concentration exceeds 400 Bq/m^3. An estimate of the number of apartments with a radon concentration above this threshold limit value, will have uncertainties due to errors in the radon measurements and in the estimation metod. A study of these uncertainties, performed in the ELIB survey [1], indicates that 90 000 - 200 000 apartments in the Swedish housing stock have a radon concentration above 400 Bq/m^3.

The lower part of Figure 2 gives examples of how density estimation can be used to describe the energy consumption for heating the Swedish housing stock, and to analyse effects of measures to decrease this energy consumption.

The left plot shows distributions of transmission losses through windows in single-family houses, before (solid curve) and after (dotted curve) upgrading to windows with three panes, in all single-family houses where the windows have one or two panes.

The right plot shows distributions of the gross energy consumption for single-family houses (solid curve) and multi-family buildings (dotted curve). The cuves show that the variation and average value of the energy consumption are substantially higher in single-family houses than among apartments in multi-family buildings.

5 Energy consequences of increased ventilation

Present research has shown that the problem of health risks associated with the indoor environment is very complex, and therefore technical solutions alone can probably not solve the whole problem. However, there is fairly large agreement that moisture in buildings and insufficient ventilation are factors that contribute to increased health risks, and these factors can be affected by technical means. As the assessment of the indoor air quality (performed in section 4) indicates that the ventilation is insufficient in the Swedish housing stock, it is interesting to study the concequences of increased ventilation.

This section reviews some results of a study addressing this topic [6]. The study was made for the Swedish Governmental Commission on Environmental Health [7].

In addition to the ventilation norm of 0.35 l/s,m^2 discussed above, alternative ventilation requirements have been considered, such as 0.70 l/s,m^2 and 0.15 l/s,m^2 + 10 l/s,person.

To analyse effects on the energy consumption of increased ventilation, the SIMBA model was used to estimate total annual ventilation heat losses in the Swedish housing stock. The above alternatives are included in the study, which gives the following computation cases:

- Standard norm: increased ventilation to 0.35 l/s,m^2 in all buildings
- High alternative: increased ventilation to 0.70 l/s,m^2 in all buildings
- Mixed alternative: increased ventilation to 0.35 l/s,m^2 + 10 l/s,person in all buildings

Computation results, broken down by building type and heating system, are given in the following table.

Table *1. Total ventilation heat losses in the Swedish housing stock [TWh/year]*

Type of building and heating system	Current ventilation	Standard norm fulfilled	High alternative fulfilled	Mixed alternative fulfilled
Single-family:				
Direct electricity	1.6	2.6	4.9	2.6
Heat pump	*0.4*	0.7	1.4	0.7
Individual plant	4.7	7.6	14.6	7.4
Block central	0.5	0.5	0.9	0.7
District heating	0.5	0.8	1.5	0.8
Other way	0.2	0.2	0.5	0.3
Multi-family:				
Direct electricity	0.1	0.2	0.3	0.2
Heat pump	0.2	0.3	0.5	0.3
Individual plant	0.7	0.8	1.4	O.S
Block central	0.8	1.0	1.8	1.1
District heating	7.3	8 0	13.2	*8 7*
Single-family	7.8	125	23’.8	12.5
Multi-family	9 2	10.2	17.1	11.1
All buildings	13.0	22’.7	40’.9	*23’.6*

Table 1 shows that the estimated increases of the energy consumption in the Swedish housing stock, that would be caused by increasing the ventilation are:

Standard norm	22.7 – 17.0	=	5.7 TWh/year
High alternative	40.9 – 17.0	=	23.9 TWh/year
Mixed alternative	23.6 – 17.0	=	6.6 TWh/year

The possibilities of heat recovery are not considered in these estimates of the increased energy consumption. A separate computation for ventilation systems with heat recovery, indicates that the standard ventilation norm can be fulfilled without any increased energy consumption, and for the high alternative, the energy consumption would be increased by about 10 TWh/year, if ventilation systems provided with heat recovery are installed.

To achieve the considered improvements of the ventilation in the Swedish housing stock, new ventilation systems must be installed in buildings where the ventilation requirements are not fulfilled.

The investment costs for this improvement of the Swedish housing stock are considerable. For new ventilation systems with heat recovery, these costs were estimated as 62 GSEK for the standard norm, 119 GSEK for the high alternative and 67 GSEK for the mixed alternative.

6 Health and comfort aspects of increased ventilation

The following positive health and comfort effects can be obtained by increased ventilation in the Swedish housing stock:

- Moisture in the buildings would descrease, which means that the health risks from mites and mould will also decrease.

- Unhealthy pollutions (e.g. radon gas, carbondioxide and volatile organic compounds) would descrease.

- The problems from stuffy air and unpleasant odour would descrease.

There may also be negative health and comfort effects of increased ventilation, such as troubles from noise, draught, dry air and dust. These troubles would become frequent, if the ventilation is increased to a high level.

An analysis of how the troubles of the residents from dry air depend on the ventilation has been performed in the ELIB survey [6]. The results indicate that only small troubles would likely occur for a ventilation level of 0.35 $l/s,m^2$. Troubles from noise, draught and dust are also likely to be small for this ventilation level. A conclusion from this discussion is that the positive effects will be much more important than the negative effects, if the ventilation is increased to the norm level 0.35 $l/s,m^2$.

7 Discussion

The paper gives examples of the usefulness of statistical modelling and simulation techniques in research concerned with properties of the Swedish housing stock, such as energy efficiency and indoor climate.

To assess the indoor air quality, density estimation is used to present data from indoor climate measurements, by easily comprehensible graphs of estimated probability distributions.

This assessment, accentuates a need to increase the ventilation in the Swedish housing stock.

Energy consequences of increased ventilation are analysed, by microsimulation techniques, for three alternative ventilation requirements.

An interesting result of the analysis is, that the ventilation can be increased to 0.35 $l/s,m^2$ in all buildings, without any increased energy consumption, if ventilation systems provided with heat recovery are installed. However, there is a considerable investment cost for this improvement of the Swedish housing stock (estimated as 62 GSEK). To make it possible to realize the improvement, efforts must be made to develop new cost effective ventilation solutions.

References

[1] Norlén U. and Andersson K. (editors) (1993): *The indoor climate in the Swedish housing stock*, Research report D10: 1993, Swedish Council for Building Research, Stockholm, Sweden

[2] Tolstoy *N.* (1994): *The condition of a building - Investigation, methodology and applications*, Doctor's thesis, Division of Building Materials, Royal Institute of Technology, Stockholm, Sweden

[3] Waller T. (1998): *Building stock analysis using microsimulation,* Licentiate thesis, Building Analysis, The Royal Institute of Technology, Stockholm, Sweden

[4] Silverman B.W. *(1986): Density Estimation for Statistics and Data Analysis,* Chapman and Hall

[5] Waller T. and Högberg H. (1993): Probability density estimation of the levels of indoor air quality variables, *The 6th International Conference on Indoor Air Quality and Climate,* Helsinki, Finland, July 4-8, 1993

[6] Norlén U., Andersson K., Hjalmarsson C., Högberg H., Nilson A. and Waller T. (1996): *Konsekvenser av att öka ventilationen i bostadsbeståndet,* Centre for Built Environment, Royal Institute of Technology, Gävle, Sweden

[7] SOU 1996: 124 (1996): *Miljö för en hållbar hälsoutveckling,* Swedish Governmental Commission on Environmental Health, Ministry of Health and Social Affairs, Stockholm, Sweden

Cost efficiency and financial feasibility of retrofitting with heat insulation of existing residential buildings in İstanbul

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Abstract

Istanbul is a metropolis with twelve million inhabitants. Nearly all the existing residential buildings in Istanbul have not sufficient heat insulation, yet, affordable retrofitting a residential building with sufficient thermal insulation is in question for the households. A research project was set to develop applicable energy efficient and economic retrofitting systems for the external envelopes of the existing residential buildings in Istanbul. In the research, DOE-2 computer program was used to analyze and to evaluate the thermal performance of the buildings. The two groups of data files, the weather data file of İstanbul and the building description input file representing the existing residential buildings and the energy efficient alternative insulation and fenestration systems were prepared for the simulation. The total heat losses and savings before and after retrofitting of these buildings were calculated. Finally the economic efficiency of alternative retrofitting systems were evaluated.

In this study, a sample building is considered where the yearly energy loss is 205.43 MWh and the required energy for heating is 293.47 MWh. The referred retrofitting systems with 5 or 15 cm external heat insulation and clear or low-e double-glazing provides 145.83 MWh (49.7 %) and 181.4 MWh (61.8 %) energy savings.

The pay-back periods for the investments are 18 to 25 years for the clear and the low-e double glazing systems, 4-7 years for the insulation systems with single glazing, and 9-11 years for the insulation systems with low-e double-glazing. The present worth of the monetary equalance of the energy savings for a period of 5 years with an interest rate of 5% meet only a certain part of the initial investment for the retrofitting. The present worth of the remaining cost of the retrofitting is the amount may be paid by the present worth of household savings according to the income groups as the following:

- The lowest income households with 5% savings can pay the remaining part of the investments made for the insulation systems without double-glazing in 5 years.
- The households in the lower and the middle income groups with their 10% and 5% savings respectively can pay the required amount for the insulation systems with the alternative double glazing systems.

Therefore, the households have to be encouraged for saving, and also the costs of retrofitting systems have to be reduced by developing the cost efficient techniques in order to afford an applicable energy efficient systems for retrofitting existing buildings.

Key Words: existing residential buildings, financial feasibility, heat insulation, household savings, income distribution, insulation cost, life-cycle costing, retrofitting

1 Introduction

Istanbul is a metropolis with twelve million inhabitants. The external envelopes of most of the residential buildings were observed to be thermally uninsulated and those which were insulated unable to exceed the values determined in the national and international standards and specifications for energy conservation. Yet, affordable retrofitting a residential building with sufficient thermal insulation is in question for the households.

A research project was set to develop applicable energy efficient and economic retrofitting systems for walls, floors and roofs for the rehabilitation of external envelopes of the existing residential buildings and the squatter housing in Istanbul. The thermal performance of the existing buildings and developed alternative energy efficient retrofitting systems were evaluated. The total heat losses and savings before and after retrofitting of these buildings were calculated. Finally the economic efficiency of alternative retrofitting systems were evaluated with Life-Cycle Costing [1).

1.1 Existing residential buildings in İstanbul

A survey was carried out at certain districts in Istanbul where registered and squatter housing schemes were exist, to understand the existing situation of such buildings. Thus, series of data concerning the surrounding environment of the typical buildings; characteristics of buildings as size, number of storey, total floor area, structure, heating system; opaque and transparent components of the building, and external envelope as pitched and flat roofs, walls, windows and floors open to external environment, and the building thermal characteristics were prepared.

1.2 Computer program for the simulation

A PC version of DOE-2.1E computer program developed for the energy analysis simulation, has been used to analyze the thermal performance of the residential buildings, [2]. This program employs weighting factor method, an hourly thermal load calculation is performed based on a physical description of the building and that hourly ambient weather conditions including solar radiation. The two groups of data files, the weather data file of Istanbul and the building description input file representing the existing residential buildings in Istanbul and the energy efficient alternative insulation and fenestration systems were prepared for the simulation, [3].

1.3 Weather data and building data required for the simulation

Hourly weather data file, Test Meteorological Year-(TMY) file, containing one year of data for each weather variables, required for the simulation with DOE-2, was prepared for Istanbul. The weather variables available in the TMY files are solar time and local standard time, extraterrestrial, direct-normal and observed radiations, dry-bulb and dew-point temperatures, atmospheric pressure, wind speed and direction, sky cover and snow cover. For preparing Istanbul weather file, the measured hourly weather data were either used directly or calculated as the dew point temperature, the extraterrestrial radiation and the direct-normal radiation, [4]. The TMY weather file of Istanbul was packed in (ASCII) formats and processed with the computer program, [3].

Data for the description of each building, 'Building Description Language-(BDL) file' are required to run the DOE-2 program. The data include the location and orientation of the building; the space conditions of the building as temperature, humidity, infiltration rate, floor weight; the physical characteristics prepared according to the existing buildings; the materials used for the construction; and the transient effects of shading. Finally, the buildings data are systematically prepared according to the typified residential buildings that include settlement type, floor area, number of storey and the physical characteristics of the existing buildings in general.

2 A typical residential building and heat insulation systems for retrofitting

In this study, a five storey block of flats-(K2A) representing one of the typical existing residential buildings in Istanbul was selected as a sample building. This building is composed with reinforced concrete structure, non-load bearing external brick wall, 1.50 m. wide overhanging floors open to external enviroment, the single pane windows, four balconies in three facades of the building and the tiled pitched-roof reflects the typical properties of building stock in Istanbul.' The non-load bearing external walls of the building rendered externally and plastered internally is formed from hallow bricks with 13.5 cm thickness. The normal floor, the total floor, the total exterior wall and the total window areas are 230, 1066, 5 18 and 232 m^2 respectively. The transparency ratio for all facades is % 35 and the building width/depth ratio is 0.7.

Internal and external heat insulation systems applied with dry and wet construction were found adaptable in retrofitting the opaque components of the exterior envelope of the existing residential buildings in Istanbul. For the transparent components, single-glasses in windows and doors were replaced with clear double-glazing or double glazing with low-emissivity coating-(Low-E) applied on outer glass. Materials considered for thermal insulation were selected from among cellular polymers as extruded and beaded expanded polystyrene and mineral fiber insulators as glass or rock-wool fiber panels with thermal conductivity design value-(k) of 0.035 or 0.04 W/mK.

3 Energy losses and savings for the retrofitted sample building

The applicable heat insulation and fenestration systems determined for the retrofitting the external envelope of the sample building-(K2A) and heat loss through the building and the energy consumed for heating are given in Table 1. The clear single-glasses in windows are replaced with clear or low-e double glazing. The inner and outer surfaces of the external walls, overhanging floors, and the roof slab are thermally insulated with 3, 5, 8, 10 and 15 cm thick expanded beaded polystyrene.

The sample building was simulated with DOE-2.1E program and the energy losses are calculated for the sample building retrofitted with alternative insulation systems. The yearly energy loss is 205.43 MWh and the required energy for heating is 293.47 MWh for the existing sample building. The energy losses and the consumed energy for the alternative retrofitting systems of the sample building is given in Table1.

Retrofitting the roof slab with 3 cm. expanded beaded polystyrene (R3G1) is the least energy efficient retrofitting system which provides 18.28 MWh (6.2 %) energy saving yearly. Replacing single-pane glass with clear double-glazing conserves 44.15 MWh (15.1 %) energy. The referred retrofitting system-(DR5G2) with 5 cm external heat insulation and clear double-glazing provides 145.83 MWh (49.7 %) energy saving.

Retrofit Systems	HI, mm W	R	F	GU	YHL MWh	YECH MWh	Retrofit System	HI, mm W	R	F	GU	YHL MWh	YECH MWh
G1				5.17	205.43	293.47	IR5G2	50	50		2.81	124.66	178.09
G2				2.81	174.52	249.31	IR8G2	80	80		2.81	118.61	169.44
G3				1.81	164.39	234.84	IR10G2	100	100		2.81	116.22	166.03
1361	30			5.17	176.15	251.64	IR15G2	150	150		2.81	112.65	160.93
I5G1	50			5.17	170.98	244.26	IR3G3	30	30		1.81	122.35	174.79
I8G1	80			5.17	166.97	238.53	IR5G3	50	50		1.81	114.53	163.61
I10G1	100			5.17	165.38	236.26	IR8G3	80	80		1.81	108.48	154.97
I15G1	150			5.17	163.00	232.86	IR10G3	100	100		1.81	106.09	151.56
R3G1		30		5.17	192.63	275.19	IR15G3	150	150		1.81	102.52	146.46
R5G1		50		5.17	189.96	271.37	DR3G1	30	30	30	5.17	144.51	206.44
R8G1		80		5.17	187.90	268.43	DR5G1	50	50	50	5.17	133.94	191.34
R10G1		100		5.17	187.09	267.27	DR8G1	80	80	80	5.17	126.26	180.37
R15G1		150		5.17	185.89	265.56	DR10G1	100	100	100	5.17	123.32	176.17
D3G1	30		30	5.17	156.91	224.16	DR15G1	150	150	150	5.17	119.01	170.01
D5G1	50		50	5.17	148.91	212.73	DR3G2	30	30	30	2.81	113.71	162.44
D8G1	80		80	5.17	143.09	204.41	DR5G2	50	50	50	2.81	103.35	147.64
D10G1	100		100	5.17	140.87	201.24	DR8G2	80	80	80	2.81	95.76	136.80
D15G1	150		150	5.17	137.64	196.63	DR10G2	100	100	100	2.81	92.86	132.66
IR3G1	30	30		5.17	163.27	233.24	DR15G2	150	150	150	2.81	88.61	126.59
IR5G1	50	50		5.17	155.36	221.94	DR3G3	30	30	30	1.81	103.58	147.97
IR8G1	80	80		5.17	149.30	213.29	DR5G3	50	50	50	1.81	93.20	133.14
IR10G1	100	100		5.17	146.88	209.83	DR8G3	80	80	80	1.81	85.60	122.29
IR15G1	150	150		5.17	143.29	204.70	DR10G3	100	100	100	1.81	82.70	118.14
IR3G2	30	30		2.81	132.48	189.26	DR15G3	150	150	150	1.81	78.45	112.07

Table 1: The externally-(D) and internally-(I) applied heat insulation-(HI) systems for wall-(W), floor-(F) and roof-(R), glazing systems-(Gl, G2, G3), the total heat losses-(YHL) and the energy consumed for heating-(YECH) in a year, before and after retrofitting the building K2A. Thermal transmittance design value for glazing-(GU)

The insulated system-(DR15G3), where the external surface of the external walls, the exterior overhanging floors and the roof slab are thermally insulated with 15 cm. expanded beaded polystyrene and the single pane windows are replaced with low-e double-glazing, provides the maximum yearly energy conservation as 181.4 MWh (61.8%) energy savings. Therefore this system is considered to be the most energy efficient retrofitting system that applicable to the sample building, however, it may not be cost efficient for the user and/or for the country.

4 Life-cycle costs of retrofitting systems and paying the initial investment back

The per square meter costs of each insulation and glazing systems for energy efficient retrofitting are calculated with fixed prices and the systems having the lowest costs, highest energy savings are determined for retrofitting. The value of energy conservation and the yearly monetary savings due to the energy conservation is calculated for each retrofitting system with life-cycle costing model.

The minimum pay-back periods-(N) of the insulation with glazing systems are calculated for comparison. The aim is to look for the period in which the initial investments are met with the monetary equivalence of energy savings. The formula is:

$$N: \log [A / (A-P*I)] / \log (1+I)$$

Where, N: pay-back period, A: monetary equalance of annual energy savings
P: the initial capital invested for retrofitting, I: interest rate, considered 5%.

The pay-back periods for each insulation system with glazing for the sample building K2A are shown in Figure 1. In the building, the roof insulation-(RG1) has the least, 2 to 3 years, and the double glazing, 18 to 25 years, has the highest pay-back periods. The pay-back periods increase for the insulation systems with single glazing-(IRG1, IG1, DRG1, DG1) from 4-7 years to 9-11 years for the systems with double-glazing-(IRG3, DRG3, IRG2 and DRG2). The energy efficient retrofitting system with 50 mm thick insulation and double glazing-(DR5G2) has the pay-back period of 10 years.

Five years period is generally considered appropriate for the pay-back of the thermal retrofitting of existing buildings. Therefore, this study was carried out to answer the question "can the households afford the initial investment of an applicable energy efficient retrofitting system with both the energy savings provided by the retrofitting system and the savings from their household incomes during a period of 5 years?"

As it is seen in Figure 1, the most cost efficient heat insulation thickness for each retrofitting system is between 5 to 8 cm. Therefore, 5 cm. heat insulation and 5 years pay-back period are considered fixed parameters for the study.

4.1 Income distribution and household savings

Inequality of income distribution among the individuals is an economical fact of life. In the cities, the income groups share of the gross national product of Turkey is as follows:

	Normal	Cumulative
Lowest income group (first 20%)	4.8 %	4.8 %
Lower income groups (second 20%)	8.2 %	13.0 %
Middle income groups	11.9 %	24.9 %
High income groups	17.9 %	42.8 %
Highest income groups (last 20%)	57.2 %	100 %

The "Gini Rate" which is high as 0.51 shows the level of inequality.

Even though many households living in cities borrow money from family relatives, banks, etc., the principal source of any investment for financing remains that of the savings acquired by the households. The general findings show that the lowest income group consumes all their income or do not save any amount while the lower income and the middle income group may save 5 to 15 %, [5]. This is also the case for Turkey. A study carried out at Pınar, an old squatter housing district in Istanbul, showed that the households save to improve their housing. See Figure 2 for the saving tendency of the household in Pınar district, [6]. However, they will not spend all their savings for the retrofitting of their houses.

4.2 Paying the initial investments back

The present worth of the monetary equalance of the energy savings-(P_{es}) for a period of 5 years with an interest rate of 5% will meet a certain part of the initial investment-(P_{ic}) for the retrofitting. In these conditions, the present worth of the savings is P_{es}:A×4,329

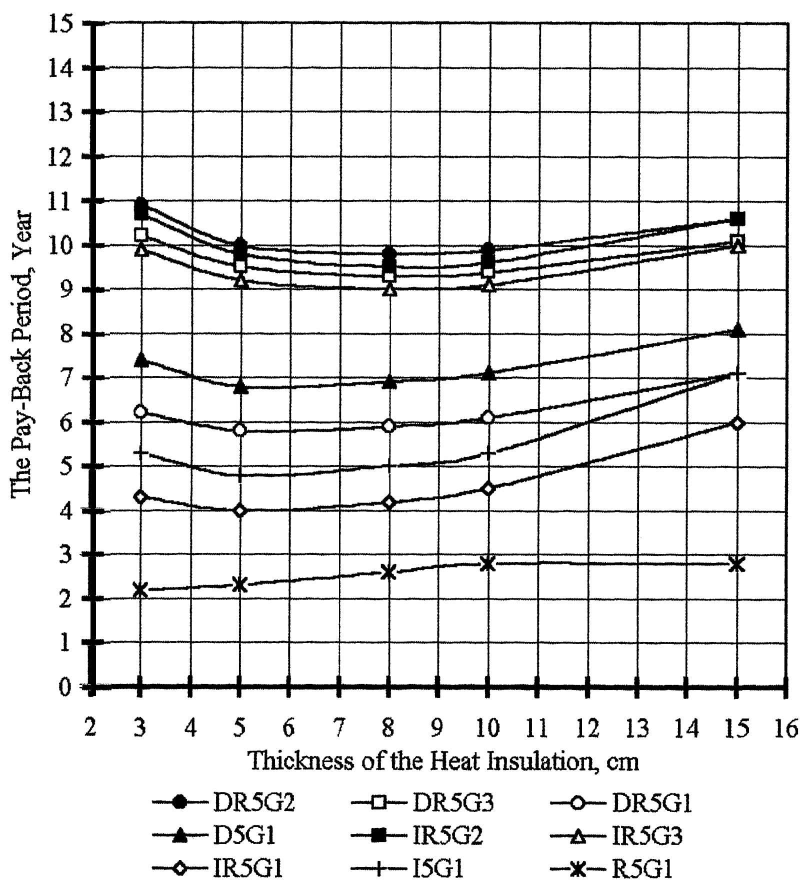

Figure 1: The pay-back periods of alternative retrofitting systems of the sample building K2A. The pay-back periods of the clear and low-e double-glazing-(G2, G3) are 25 and 18 years.

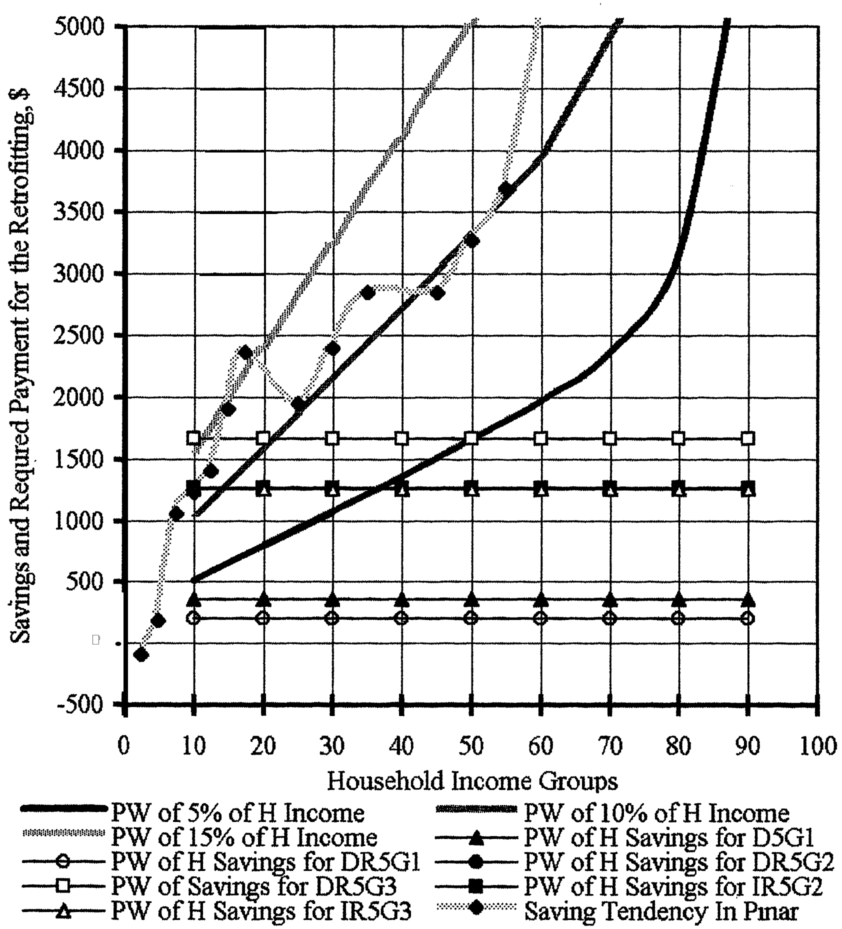

Figure 2: The present worth-(PW) of 5, 10 and 15 % of households' income-(HI) for the period of 5 years, the savings tendency in Pinar disrict and the required payment for the alternative retrofitting systems

where "A" is the cost of yearly energy savings, [7]. Hence, the present worth of the remaining cost of the retrofitting-(P_{ic}-P_{es}) is the amount may be paid by the present worth of 5 to 15% the household income-(P_{lhs}) for a period of 5 years. The yearly monetary savings due to the energy conservation is calculated for each retrofitting system Table 2. It shows that retrofitting with 5 cm insulation without new glazing-(DR5G1) is the most cost effective as it requires minimum amount of household savings to pay the remaining $2018 in 5 years. Among the alternatives, retrofitting system with low-e double-glazing-(DR5G3) is the least cost effective but most energy efficient system as it can be acquired with the maximum household savings of $17158 for the sample building.

Retrofit Systems	YHL MWh	YECH. MWh	YES MWh	MEC $\Year	PWE $\5Years	P_{ic} $	P_{lhs} $
Existing	205.43	293.48	6.00				
D5G1	148.91	212.72	so.75	2 753	11917	15 504	3 586
DR5G1	133.94	191.34	102.14	3482	15 073	17 091	2 018
DR5G2	103.35	147.64	145.84	4 972	21 523	38·179	16 656
DR5G3	103.58	147.97	145.50	4 960	21473	38632	17 158
IR5G2	124.66	178.09	115.39	3 934	17 029	29655	12 626
IR5G3	114.53	163.61	129.86	4 427	19 165	31747	12 582

Table 2: The present worth of energy savings-(EWE) for a 5 years with an interest rate of 5%, the initial investments of each retrofitting systems-(P_{ic}) and the present worth of the loan that is to be paid by the household savings-(P_{lhs}) for the sample building; yearly energy savings-(YES), monetary equivalence of the energy savings-(MEC).

The yearly disposable household incomes are calculated for each income groups by considering the Gross National Product [6]. The present value of 5 to 20% of household incomes are calculated as the present value savings with an interest rate 3 % of all income groups in order to put forward the household savings that can pay the amount of loan required for each retrofitting systems, Table 3.

Income Groups	YDII	YDHI	YDHI as %, $				PW of DHI for 5 Years, $			
	$	$	5	10	15	20	% 5	% 10	% 15	% 20
Lowest income groups	695	3473	174	347	521	695	795	1 591	2 386	3 182
Lower income groups	1 187	5934	297	593	890	1 187	1 359	2 718	4 076	5 435
Middle income groups	1722	8611	431	861	1 292	1 722	1972	3 944	5916	7 888
High income groups	2 591	12953	648	1295	1943	2591	2 966	5932	8 898	11865
Highest income groups	8 278	41390	2 070	4 139	6 209	8 278	9478	18 957	28 435	37 913

Table 3: The yearly income of individuals-(YDII) and households-(YDHI), 5' to 20 % of household incomes-(YDHI), and the present worth-(PW') of 5 to 20 % of a household income-(DHI) for a period of 5 years with an interest rate of 3%.

The present worth of 5 to 15% of the household incomes for a period of 5 years and the present worth of the retrofitting system costs that remained after the present worth of the monetary equivalence of the energy savings is deducted from the initial investment are displayed in Figure 2. The all households with 5% savings can pay the remained amount of investments made for the insulation systems with the double-glazing, except the lowest income groups.

Natural night ventilation and thermal inertia

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Abstract

The objective of this study is to propose a simplified characterization of the thermal inertia, as part of the implantation of a system of summer refreshment by night cooling ventilation. On the low of a previous study, realized with the help of the modal analysis, the interactions between the thermal inertia of a building and the night cooling ventilation are clarified. Then, it is shown that the notion of useful thermal mass is here maladjusted to take into account the thermal inertia of the building and that it would suit to substitute it an approached calculation of the main time-constant of the building.

More, the necessity to add a parameter characterizing the rapid dynamics of the air temperature of a zone is justified. Finally, a characterization of the thermal inertia based on the three criteria calculation is proposed. An approached value of the time-constant during the period of night cooling and out of this period and an approached value of the height of the line associated to the rapid dynamics.

Keywords: time-constant, night cooling ventilation, pilot study, rapid dynamics, summer refreshment, thermal inertia.

1 Introduction

Taking into account the thermal inertia during the conception of a building remains a delicate problem. In fact, the thermal inertia is not accessible directly ; alone its consequences are observable. Its effects can be very different according to the nature of the outdoor thermal solicitations to which the system is submitted and the position of observation of the response that we have choseen [1, 2].

However, at the beginning of a project, the designer has to use simplified criteria so as to direct its study. The useful thermal mass or an approached value of the main time-constant are generally used to anticipate effects of the thermal inertia. But, these global criteria do not take into account the nature of thermal solicitations and appear often insufficient [3].

In previous works [4, 5], we have proposed a simplified characterization, of the thermal inertia of a one-zone building, that can be used in the pilot project and takes into account the nature of thermal solicitations. The aim of this paper is to apply these works to the natural night cooling ventilation of buildings.

2 The summer refreshment by night cooling ventilation

This process of refreshment, consists in increase the air exchange rate during the unoccupied period of night in order to eliminate the heat that was stored in the building mass during the day. Blondeau and al [6] have shown that some sites are more favourable to the implantation of a night cooling ventilation. Indeed, a raised value of the difference of the average temperature between the day and the night gives a best efficiency to this technique. These same authors have proven also that the night ventilation will give best result if the building has relatively important solar protections. An experiment directed by Sperandio and al [7] has shown that the good distribution of the fresh air in the building increases the global efficiency of the system ; this technique will be therefore more efficient for the small volumes.

In order to avoid discomforts in the beginning of the occupied period, this technique requires adapted scenarios of regulation. More, the utilization of an air conditioning in complement of this system is generally not desirable, because the air conditioner modifies the past thermal behaviour of the building therefore annihilates a susceptible gain part to be realized by the night ventilation.

It is obvious that potentialities of a night cooling ventilation are closely linked to the thermal inertia of the building, but we often forget that the increased air exchange rate modifies characteristics of the initial thermal system and therefore its thermal inertia. In a previous study [8], we have analyzed the role of the air exchange rate on the dynamics of the temperature of a zone.

In the following paragraph, we will use results of this study, in as part of the implantation of a night cooling ventilation. We will release some necessary parameters in order to take into account the thermal inertia of a building in pilot study.

3 The air exchange rate and the thermal inertia

3.1 The thermal inertia of a system

The thermal behaviour of a system in dynamic state is completely defined by the totality of these eigenvalues and corresponding eigenmnctions that are these intrinsic characteristics. They have elsewhere allowed to give the first definition of the thermal inertia [9]. Eigenvalues set the time scale of all dynamic phenomena to which the thermal system is submitted. The form and the amplitude of the eigenfunctions allow to analyze the action of each mode on the different components of the system.

Natural modes, that are in infinite number, can be classified summarily in rapid modes and in slow modes. Among these, some are dominant and others weaks. In fact, alone some modes sufficed to reconstitute correctly the dynamic state. The slow dynamic is usually dominated by several modes of large time-constants ; the first one is generally the most influential. This first mode translates in fact the importance of the coupling by the air of walls delimiting the zone. The study of natural modes shows also that there exists always a dominant rapid mode associated to the time-constant τ_r around of which we will be able to amalgamate the rapid dynamics. This mode will be all the more rapid that the coupling air - walls will be strong.

We show that the notion of useful thermal mass, that characterizes in fact only the low dynamic, is here maladjusted to take into account the thermal inertia of a building in the case of the installation of a night cooling ventilation

3.2 Action of the air exchange rate on time-constants

We have shown in [8] that when the air exchange rate increases, all natural times corresponding to the natural modes decrease and have as limit a ***local*** value of a wall of the system. Especially the ***global*** first time-constant tends to the largest time-constant of walls.

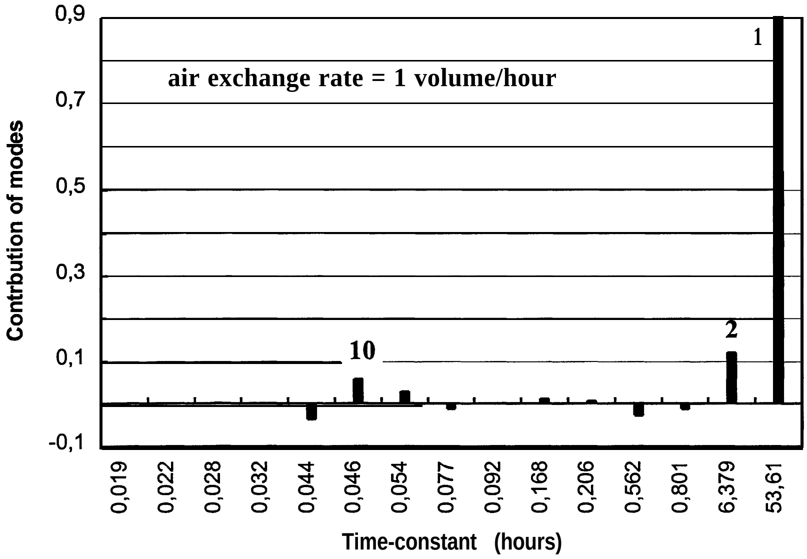
As an example, the table 1 gives the twelve first time-constants of a cell for air exhange rates of 1, 5 and 10 volumes per hour. The cell has a volume of 200 m^3 insulated by the interior with 2 cm of insulator. The external wall has a surface of 150 m^2 and the cell contains 60 m^2 internal walls of 8 cm of concrete.

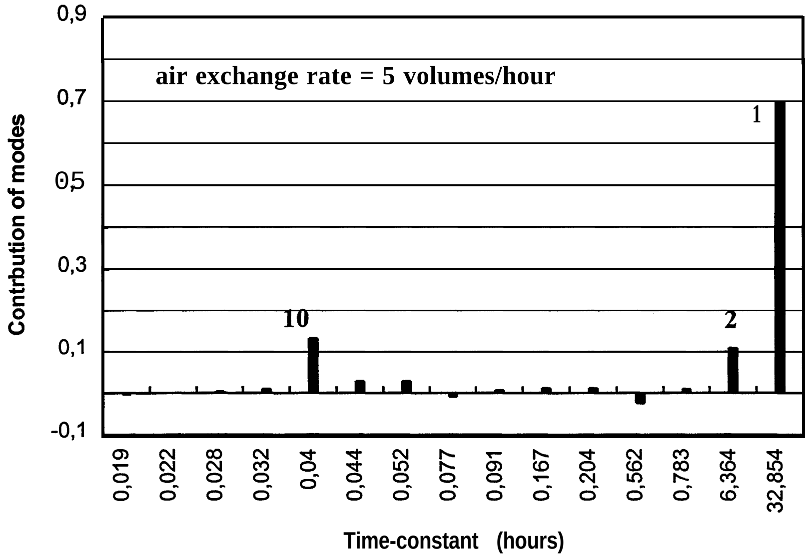
Mode number	**Air exchange rate (volume per hour)**		
	1	**5**	**10**
1	53.61	32.85	25.01
2	6.38	6.36	6.35
3	0.801	0.783	0.769
4	0.562	0.562	0.562
5	0.206	0.204	0.202
6	0.168	0.167	0.167
7	0.092	0.091	0.091
8	0.077	0.077	0.077
9	0.054	0.052	0.05 1
10	τ_r = 0.046	0.044	0.044
11	0.044	τ_r = 0.040	τ_r = 0.035
12	0.032	0.032	0.03 1
approached τ_1	49.87	24.68	15.13

Table 1: Evolution of the time-constants (hours) as a function of the air exchange rates

In fact, for higher air exchange rates, the low dynamic will be marked by a disorderly time evolution of the walls. Indeed, the air do not insures its role of coupling between walls. These latters will be therefore thermically dissociated. The notion of useful thermal mass, that supposes implicitly a good coupling air - walls, appears in this case maladjusted to translate modifications of the thermal inertia as a function of the air exchange rate. Van der Mass and al [10] had already noticed it on experimental tests realized on a building of the Leso in Lausanne.

An approached calculation of the time-constant of the dominant slow mode, integrating variations of the air exchange rate, would allow a best taken into account of this phenomenon as it is shown in the last line of the table 1. It would suit here to undertake this calculation during the period of night ventilation and out of this period.





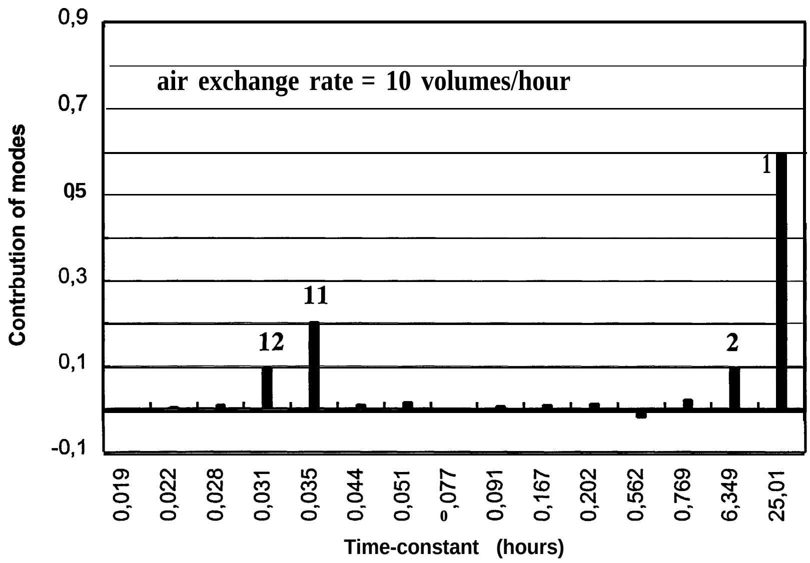


Figure 1: Response spectrums of the indoor air temperature of a cell, with interior insulation, as a function of the air exchange rate

3.3 Action of the air exchange rate on the temperature response of a zone

During the implantation of a night cooling ventilation, it is important to understand the air temperature response of a zone under the action of the outdoor temperature solicitation.

At this end, the figure 1 represents the spectrums of the air temperature response of a zone for different air exchange rates. We can notice that the importance of the first mode is less and less pronounced when the air exchange rate increases contrary to the dominant rapid mode τ_r (see § 3.1) that have an action more important on the air temperature response of the zone. For a rate of 1 volume per hour, the rapid response represents 4 % of the rise to the steady state, on the other hand it happens to 35 % for a rate of 10 volumes per hour.

In period of night ventilation, the rapid dynamic represents an important part of the air temperature response of a zone. It proves therefore necessary to attach to the characterization of the thermal inertia a parameter that takes into account the rapid response of the temperature of zone in period of night ventilation.

4 Simplified criteria taken into account the thermal inertia

According to the conclusions of the previous paragraph, we propose to characterize the thermal inertia by the three following parameters :

τ approached value of the time-constant characterizing the low dynamic during the occupied period of no-ventilation.

τ_s approached value of the time-constant characterizing the low dynamic during the unoccupied period of night ventilation.

r the part share taken by the rapid dynamic in the air temperature response of the zone during the unoccupied period of night ventilation.

4.1 Calculation of approached time-constants

This calculation can be carried out by using a property of temperature fields demonstrated by Sicart [9]. When a temperature field has the form of a natural mode, the ratio of the energy contained in the system by the outgoing flow is equal to the time-constant associated to this mode. This property allows an approached calculation of the time-constant of the dominant mode that has a close form to the one of the steady state associated to the convective power solicitation of heating. The methodology of this calculation is detailed in [1, 4].

4.2 Calculation of the parameter r

We can use as indicatory r an approached value of the height of the line (i.e the contribution of the natural mode), associated to the rapid dynamics, of the spectrum of the air temperature response of a zone to an outdoor temperature solicitation [4].

This criterion r can be calculated by noticing that the part taken by the rapid dynamics in the air temperature response of a zone can be approached by the ratio of the heat flow brought to the air by the flow exchanged with walls at the outdoor air temperature.

$$r = \frac{Ca.Qr}{Ca.Qr + Kv.Sv + \sum_k hi_k A_k}$$

with

Ca the calorific capacity of the air (Wh / m^3°C)

Qr the air exchange rate (m^3/h)

Kv the the heat transmission coefficient of glazings (W/m^2°C)

Sv the surface of glazings (m^2)

hi_k the superficial exchange coefficient of the wall (k) (W/m^2°C)

A_k the surface of the wall (k) (m^2)

The thermal resistance of the interior insulating is integrated in the coefficient hi_k.

For the example quoted in the paragraph 3.2, τ = 49.9 h, τ_s = 15.1 h and r = 0.365

5 Conclusion

We have shown, in this paper that the notion of useful thermal mass is insufficient to take into account the thermal inertia, in pilot study, in the case of the presence of a night cooling ventilation. It would suit to substitute it the approached calculation of the dominant time-constant of the low dynamic that while remaining simple, presents the advantage to integrate dynamic characteristic variations of the thermal system during the variation of the air exchange rate.

More, it is indispensable to add there a parameter characterizing the rapid dynamics during the period of night ventilation, what can be made simply by an evaluation of the height of the line associated to the dominant rapid mode.

Finally, to be really usable, this method will have to be linked to weather report conditions of the site and to the solar protections rate.

References

1. Lefebvre, G. (1989) Caracterisation de l'inertie thermique d'un batiment par analyse modale. *Revue générale de thermique, No. 332-333.* pp. 501-512.
2. Neirac, F.P. (1989) Approche theorique et experimentale des modeles reduits du comportement thermique des batiments. *These de doctorat,* Ecole des Mines de Paris.
3. Depecker, P., Brau, J. et Rousseau, S. (1982) Pertinence des modeles simplifies pour la description du comportement des batiments en regime thermique variable. *Annales de l'Institut Technique du Bâtiment et des Travaux Publics, No. 404.* pp. 139-150.
4. Douzane, 0. (1995) Contribution à la prevision du comportement thermique dynamique d'un batiment monozone à l'aide de criteres approchés ; applications aux methodes de dimensionnement. *These de doctorat,* Universite de Picardie Jules Verne.
5. Roucoult, J.M., Douzane, O. et Langlet, T. (1994) Caractérisation simplifiee de l'inertie thermique d'un batiment monozone. *Revue Générale de Thermique,* n° 390 -391. pp.406-413.
6. Blondeau, P. , Sperandio, M. et Sandu, L. (1994) Potentialites de la ventilation nocturne pour le rafraîchissement des batiments du sud de l'Europe. *European Conference on energy performance and indoor climate in buildings,* Lyon, tome 3, pp. 854-859.
7. Sperandio, M., Blondeau, P. et Allard, F. (1995) Experience de surventilation nocturne pour l'amelioration des conditions de confort en été. *Rencontre Association Universitaire de Genie Civil,* Nantes, pp. 183-l 87.
8. Roucoult, J-M., Douzane, O. et Langlet, T. (1996) Analyse du comportement en regime dynamique d'un Batiment monozone soumis à une surventilation de nuit. Colloque de la Société Française des Thermiciens, Toulouse, pp.336-342.
9. Sicart, J. (1984) Analyse modale appliquee à la thermique, fondements analytiques et application au batiment. *These de docteur-ingenieur,* Paris VI.
10. Van der mass, J., Florentzos, F., Rodriguez, J.A. et Jaboyedoff, P. (1994) Passive cooling by night ventilation. *European Conference on energy performance and indoor climate in buildings,* Lyon, Tome 3. pp. 646-65 1.

Solar thermal storage with phase change materials in domestic buildings

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Abstract
This paper summarises the investigation and analysis of a solar space heating system incorporating phase change materials for use in domestic buildings in the UK. Encapsulated phase change material modules designed to absorbed heat from water pipes are used for the thermal storage of solar energy. By choosing a suitable phase change material to take advantage of the latent heat absorbed during phase change of the material from solid form to liquid form, a large quantity of daytime solar energy can be stored and used for space heating at a later time. Conventional roof mounted flat plate solar panels have been selected for solar collection and the thermal energy is transferred to the phase change material through a series of pipes under the floor.

A dynamic modular simulation program is used to study the performance of the proposed space heating system. Components which simulate the two-dimensional heat transfer and the phase change process are established. Seven system configurations are analysed and their performances and energy savings are evaluated.

Results indicate the performance of the proposed system is affected by the attainment of phase change temperature in the phase change material. The generation of this phase change temperature is related to the area and efficiency of the solar panel, the temperature gradient along the length of pipe and the heat transfer characteristics of the equipment. The proposed system, which uses commonly available commercial materials and equipment, demonstrated to be viable. The results show the thermal effectiveness of phase change material and significant amount of energy saving can be achieved.

Keywords: Thermal storage, phase change materials, solar space heating, computer simulation

1 Introduction

Latent heat is the large quantity of energy which needs to be absorbed or released when a material changes phase from solid state to liquid state or vice versa. The magnitude of the energy involved can be demonstrated by comparing the sensible heat capacity of concrete with the latent heat capacity of a phase change material, calcium chloride for instance. Concrete has a sensible heat capacity of approximately 1.0 kJ/kgK [1] whereas calcium chlorine can store/release 190 kJ/kg [2] of energy during its phase change transition. It is obvious that any energy storage systems incorporating phase change materials will comprise significantly smaller volumes when compared to alternative materials storing only sensible heat.

One of the potential applications of phase change materials is the storage of solar energy. This is particularly suitable for dwellings where the roof can be used to collect the solar energy during the day, which is then used at a later time. As solar energy is a renewable energy source, reliance on fossil fuels and the greenhouse gas emissions can thus be reduced.

It is difficult to assess the performance of solar energy storage by phase change materials due to the dynamic nature of the system and the large number of variables involved. The main objectives of this study is therefore twofold. Firstly, to demonstrate the use of a computer simulation tool for the study of solar thermal storage systems incorporating phase change materials. Secondly, to use the simulation tool for investigating the performance of a proposed system. The following sections introduce the basic concepts of modular simulation, the functions of the modular components and the construction of the computer simulation models. The computer models of different configurations of the proposed system are simulated, the results are analysed and conclusions are summarised.

2 Simulation program

The simulation program used in this study is a dynamic modular simulation program [3]. The modular concept is to represent each component of a system as one module such that they can be linked together to form a complete network and subsequently the behaviour of the system can be studied. Each component is "self-contained" in the sense that information can only be conveyed through connecting nodes, the components react according to the information received and subsequently write new information to the nodes.

3 The components

Solution algorithms are contained within the component for describing its process. The component reads information from its nodes, parameters and internal states. The outputs are sent to the nodes and internal states.

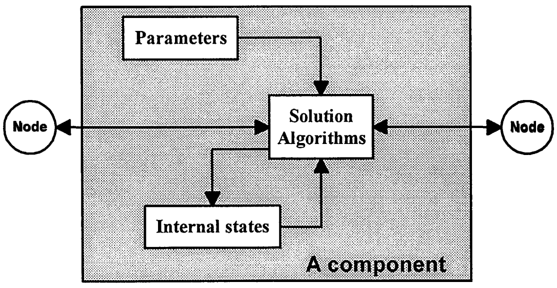


Figure 1 A component

Figure 1 shows the conceptual configuration of a component.

3.1 Pipe with phase change material

This is formed by two concentric pipes (see figure 5b) with the phase change material sandwiched between the two pipes. This component computes: 1) the radial heat transfer between the fluid, the phase change material and the ambient; 2) the heat transfer due to latent heat at phase change temperature; 3) the axial heat transfer along the length of the pipe and; 4) the water flow generation due to pressure difference exerted at its two ends. The descriptions and algorithms for these four functions are as follows:

1) Radial heat transfer

The pipe with phase change material calculates the radial heat transfer from the water inside the pipe to the surrounding air by the lump parameter procedure [3]. Figure 2 is the circuit representing the one dimensional radial heat flow of a section of the pipe. The governing radial heat transfer equations for a section j of the phase change material pipe are [4]:

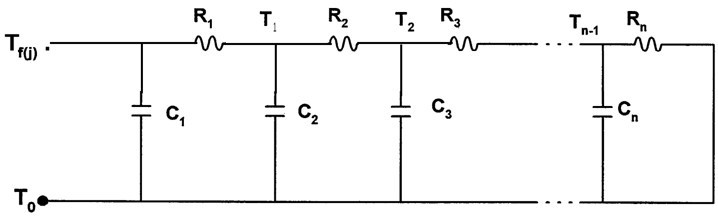


Figure 2 Radial heat flow network

$$m_f C_f (T_{f(j)} - T_{f(j-1)}) = C_1 \frac{dT_{f(j)}}{dt} + \frac{T_{f(j)} - T_1}{dt}$$

$$\frac{T_{f(j)} - T_1}{R_1} - \frac{T_1 - T_2}{R_2} = C_2 \frac{dT_1}{dt}$$

$$\frac{T_{(i-2)} - T_{(i-1)}}{R_{(i-1)}} - \frac{T_{(i-1)} - T_i}{R_i} = C_i \frac{dT_{(i-1)}}{dt}$$

$$\frac{T_{(n-2)} - T_{(n-1)}}{R_{(n-1)}} - \frac{T_{(n-1)} - T_o}{R_n} = C_n \frac{dT_{(n-1)}}{dt}$$

m_f = mass flow rate of fluid [kg s^{-1}]
$R_1 = R_{si} + 0.5\, R_{met}$ [K W^{-1}]
$R_2 = 0.5(R_{met} + R_{pcm})$ [K W^{-1}]
$R_{3\ to\ n-1}$ = thermal resistance of phase change material [K W^{-1}]
$R_n = R_{so} + 0.5R_{met}$ [K W^{-1}]
$C_1 = M_f C_f$ [J K^{-1}]
$C_2 = M_{met} C_{met}$ [J K^{-1}]
$C_{3\ to\ n}$ = thermal capacity of phase change material [J K^{-1}]
T = temperature [K]
M = mass [kg]
C = specific heat capacity [J kg-' K^{-1}]
f, met, pcm = subscript for fluid, metal, phase change material
0, si, so = subscript for outside, inside surface, outside surface. All surface heat transfer coefficients are taken from the CIBSE guide [5].

2) Phase change heat transfer

When phase change occurs the latent heat effect is significantly greater than the sensible heat, hence the radial temperature distribution within each thin layer of the phase change material is assumed to be uniform [6]. This temperature uniformity is further maintained by subdividing the phase change material into thinner layers as shown in figure 2.

At phase change temperature $T_{phç}$ the heat energy is used for the phase change process. When the time step is small:

If $Q_{lhtmax} > Q_{lht} > 0$

$T_{pcm} = T_{phc}$

$Q_{lht} = \int W_{pcm}\, dt$

Q_{lht} = latent heat content of the phase change material [J kg^{-1}]
Q_{lhtmax} = maximum latent heat capacity of the phase change material [J kg^{-1}]
T_{pcm} = temperature of the phase change material [K]
W_{pcm} = rate of heat flow to the phase change material [Wkg^{-1}]

3) Axial heat transfer

To take into account the axial temperature gradient that exists in a long pipe and the narrow temperature range of the phase change process, each pipe component is subdivided into a number of sections along its length. The number of sections in each pipe is 16 but it can be increased by emulating a single pipe with several smaller pipes connected in series.

4) Water flow generation

The D'Arcy equation, which includes the static pressure generated by vertical pipes, is used:

$$Rm^2 = |(P_1 - P_2)+P_h|$$

P_1, P_2 = pressure at either ends of the pipe [Pa]
R = flow resistance of the pipe [Pa s^2 kg-“]
P_h = static pressure [Pa]
m = mass flow rate of fluid [kgs^{-1}]

3.2 Solar panel

The basic equation for the solar heat Q collected from unit area of the solar panel is [7]:

$$Q=F^*[I(t^*a)-U(T_i-T_a)]$$

F = collector heat removal factor
t*a = product of transmittance and absorptance
U = the upward heat loss coefficient [$Wm^{-2}K^{-1}$]
T_i, T_a = water inlet temperature and atmospheric air temperature [K]
I = total solar irradiance [Wm^{-2}]

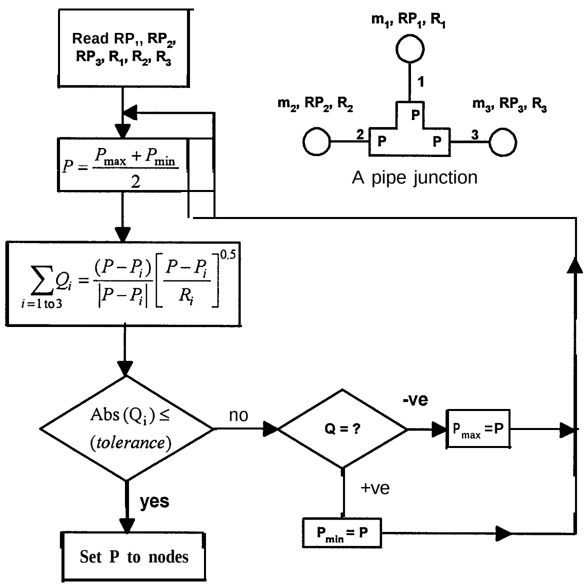


Figure 3 Flow chart for solving pressure at pipe iunctions

3.3 Pipe junction

The pipe junction reads the mass flow rates m_i, remote pressures RP_i and pipe resistances R_i sent to it by the pipes on its branches and adjusts its own pressure in such a way that the sum of the mass flow will be zero. This new pressure P is found by a bi-sectional iterative method [3]. The flow chart in figure 3 shows the principle to achieve the solution.

3.4 Pump and fan

The pump or fan provides motive force for fluid, generates a pressure which drives flow through the attached components. The pressure developed by a pump or fan is a function of the flow it is called upon to deliver and is related to its characteristics. The equations governing the pump/fan component are:

$$P_1 - P_2 = (am^2 + bm + c)$$
$$P_3 - P_1 = R_1 m^2$$
$$P_2 - P_4 = R_2 m^2$$

P_1 to P_4 = total pressure [Pa]
m = mass flow rate of water [kg s^{-1}]
a, b, c = constants

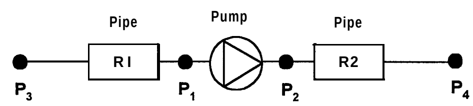


Figure 4 Pump with connecting pipes

Melting point	29°C
Heat of fusion	190.8 kJ/kg
Specific heat capacity	2.1 kJ/kgK (liquid at 48°C) 1.42 kJ/kgK (solid at 16°C)
Thermal conductivity	0.54 W/mK (liquid at 39°C) 1.008 W/mK (solid at 23 °C)
Density	1562 kg/m’ (liquid at 32°C) 1820 kg/m^3 (solid at 23°C)

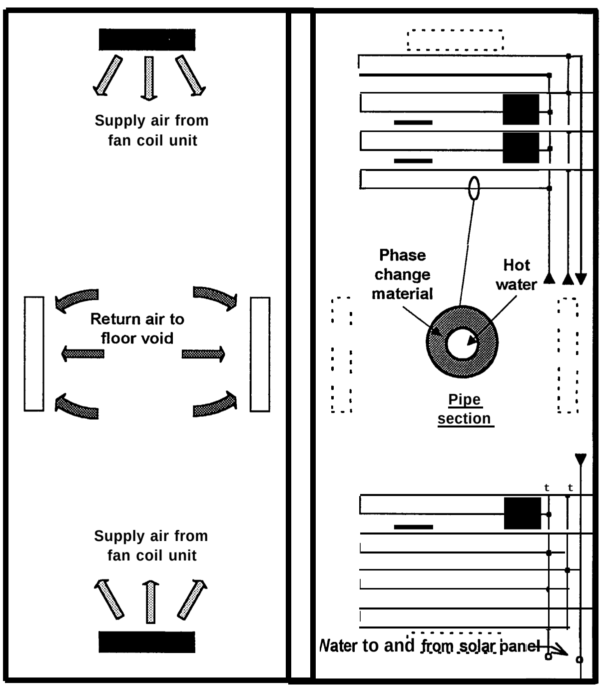
Table 1 Properties of phase change

3.5 Weather

The solar radiation data are based on the CIBSE guide section A2 [8] basic direct solar irradiances for southern England between October and March. The dry bulb temperatures are simulated using the factors given in the same section.

4 The model

The proposed building used in the simulation model is a typical two bedroom bungalow of 7m x 10m x 2.4m high. The sitting/dining room, which is to be heated by phase change material, has a measure of 3m x 7m. Solar panels of a total area of 20m^2 are installed on the south facing pitched roof. The phase change material is placed inside the house under the floor of the sitting/dining room. The phase



(a) (b)

Figure 5 Plans of room layout and phase change material under the floor void change material is contained within the pipe walls of two concentric copper pipes (see figure 5b). A pump in the loft circulates water between the solar panel and the pipes containing the phase change material. Two floor-standing fan coil units located at opposite sides of the room provide space heating for this room. Dampers are used to control air supply to the fan coil units. Air is drawn from the floor void below the units as long as the air temperature in the floor void is above the room air temperature. Otherwise air is drawn from the room through the front faces of the units. Any deficiency in heating requirement is complemented by the heating coils inside the fan coil units. Figure 5a illustrates the layout of the fan coil units and return air grilles. Figure 5b shows the layout of water pipes containing phase change material in the floor void and an exploded view of a pipe section.

5 Simulation

Flow networks similar to figure 6 are constructed using the components created in section 3. As preliminary studies indicated the importance of water temperature within the circuit, the investigation therefore focuses on the solar panel configuration and the length of the pipe containing the phase change material. Seven cases listed in table 2 are simulated to compare their performances. As effect of the latent heat is much greater than the sensible heat, only latter is considered in the simulation.

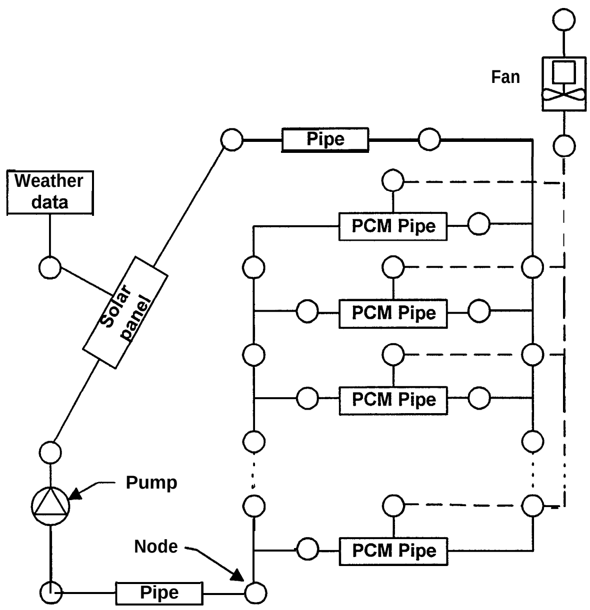


Figure 6 Computer simulation model

The space heating load of the building is separately analysed using the National House Energy Rating (NHER) program [9]. The single glazed solar panels used in the models have a total area of 20 m^2, with a heat removal factor of 0.93, heat loss coefficient of 7.0 W/m^2K and the product of transmittance and absorptance of 0.8. There are four parallel phase change material pipes linked to each solar panel. The phase change material used in this study is calcium chloride ($CaCl_2.6H_2O$) and its properties are shown in table 1 [2].

Case	Solar panel	PCM pipe	Total length (m)	Total volume of phase change material (m^3)
1.	5 m^2 x 4 nos.	3m x 16 nos.	48	0.09
2.	5 m^2 x 4 nos.	6m x 16nos.	96	0.18
3.	5 m^2 x 4 nos.	9m x 16 nos.	144	0.27
4.	5 m^2 x 4 nos.	12m x 16 nos.	192	0.36
5.	10 m^2 x 2 nos.	6m x 8 nos.	48	0.09
6.	10 m^2 x 2 nos.	9m x 8 nos.	72	0.14
7.	10 m^2 x 2 nos.	12m x 8 nos.	96	0.18

Table 2 Case studies

6 Results and discussion

The result from the NHER Program indicates the model room has a space heating load of 13.3 MJ when it is heated for eight hours with average outdoor and indoor temperatures of 21°C and 10°C respectively. The simulated total solar radiation reaching the solar panel on the pitched roof over 24 hour periods for the design days of the six months for SE England, as shown in figure 7, indicates that the available solar energy is well above that required for space heating. However under 2% of the total solar energy is converted into latent heat in the seven case studies.

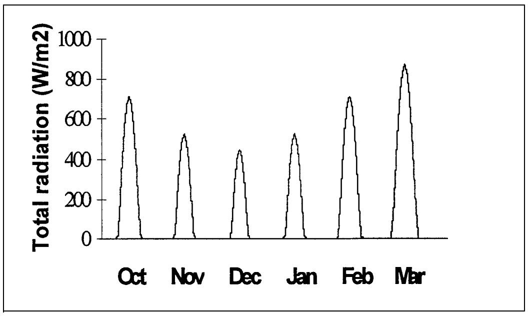


Figure 7 Total radiation on the solar panel

Based on the space heating load established from the NHER program, approximately 70 kg of phase change material is sufficient to provide the space heating requirement by latent heat alone. The amount of phase change material can be used in practice is restricted by the space of the floor void and the area of solar panel that can be mounted on the pitched roof.

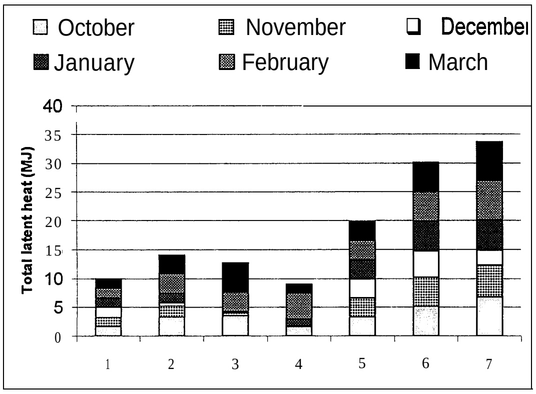


Figure 8 Latent heat captured

Figure 8 shows the amount of latent heat being captured in each of the seven cases (table 1) under investigation. Results indicated that for the same amount of solar radiation, the main factors affecting the efficiency of theses storage systems are water temperature, heat transfer between the pipe walls and phase change process within the material itself. The amount of latent heat stored can vary significantly even when the same amount of phase change material is used in the systems as indicated by case 2 and 7. The use of the larger size solar panel in cases 5 to 7, which results in higher flow temperature, is more favourable for the latent heat storage. Lower water flow rates in return for higher water temperatures could have been used but this would change the heat transfer coefficients and affect the comparisons in the case studies. When evaluating performance per unit length of pipe, it appears that 3 m pipe has the highest latent heat content for cases 1 to 4 and the 6m pipe for cases 5 to 7. Based on the calculated space heating load and excluding the pump and energy, the savings due to solar thermal storage with phase change material are between 18 to 32% (figure 10).

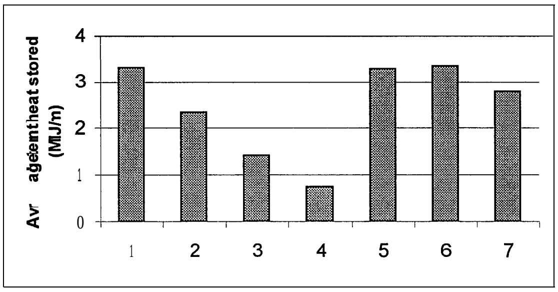


Figure 9 Latent heat stored per unit length

7 Conclusion

Due to the dynamic nature of the solar radiation, the two-dimensional heat transfer and the phase change process, the study of thermal systems involving phase change materials and solar energy is a complex and tedious task. This paper illustrates how such kind of analysis can be performed by means of a modular simulation program.

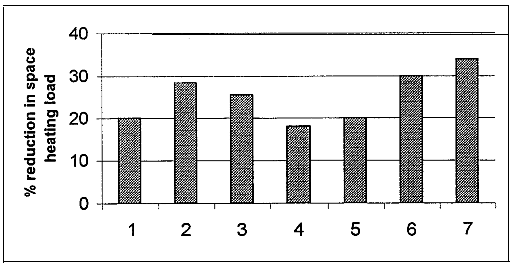


Figure 10 Energy reduction

This study demonstrates not only the viability of incorporating phase change material in domestic buildings to reduce the space heating energy consumption, it also shows that such a system can be constructed using commonly available materials and equipment. Results indicate the performance is affected by the attainment of phase change temperature through heat transfer from the water contained in the pipe to the phase change material. The generation of this phase change temperature is related to the area and efficiency of the solar panel, the temperature gradient along the length of pipe and the heat transfer efficiencies of the equipment. This study has laid the groundwork for further research on the use of phase change material in buildings. As domestic space heating accounts for a large proportion of the energy use in the UK, the exploitation of solar energy in conjunction with the storage potential of phase change material is a design option ought to be explored.

8 References

1. CIBSE (1986) Guide A3 *Thermal properties of building structures* The Chartered Institution of Building Services Engineers, London.
2. Lane G.A. (1983) *Solar heat storage:Latent heat materials Vol. 1 Background* CRC Press:Florida.
3. Ip K.C.W. (1991) *Dynamic modular simulation of variable water and air volume flow systems in buildings* PhD thesis, University of Bristol, UK.
4. Ip K.C.W., Day B., Richardson D. (1989) *Fluid flow and heat transfer inpipework systems: I Mathematical model for dynamic modular simulation* Building Services Research and Technology, Vol. 10 no. 4 1989.
5. CIBSE (1986) Guide C3 *Heat Transfer.* The Chartered Institution of Building Services Engineers, London.
6. Chandra S. et al (1985) Thermal performance of a non-air-conditioned building with PCCM thermal storage wall *Energy Conversion Management* Vol. 25. No. 1 pp. 15-20, Pergamon Press Ltd., UK.
7. ASHRAE (199 1) Application Handbook Chapter 30 Solar Energy Utilization. ASHRAE, Atlanta, USA.
8. CIBSE (1986) Guide A2 *Weather and Solar Data.* The Chartered Institution of Building Services Engineers, London.
9. NHER (1996) NHER Evaluator. Energy software by National Energy Services Ltd. Milton Keynes, UK.

Moisture performance of retrofitted exterior walls of multi storey residential buildings in İstanbul

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Abstract

Most of the residential buildings in Istanbul need retrofitting to improve energy efficiency and indoor comfort. The placement of a thermal insulation layer either inside or outside of the wall are common retrofitting systems for the opaque component of the exterior wall. The moisture performance of those offered retrofitting systems, interacting with the existing typical wall construction of the Turkish building industry are widely unknown yet. There are also no moisture control guidelines available for retrofitting practice in istanbul.
The aim of this study is the prediction of the effects of water vapor diffusion on moisture performance of retrofitted typical wall constructions. In the study, retrofitting systems, placements of the thermal insulation layer, types of the insulation materials, their thickness and types of finishing materials are utilized as variables. The indoor climatic conditions are considered to be constant, but indoor relative humidity is altered for each case. Meteorological data for Istanbul is taken as the outdoor climatic conditions.
The moisture performance is determined with a computer simulation program using a transient, one dimensional, finite difference model for heat and moisture transfer.
In the paper the moisture distribution, expressed in relative humidity (RH), within the existing wall construction retrofitted either inside or outside with a mineral fiber or cellular plastic thermal insulation for the end of the month February is graphically presented.
When the indoor mean relative humidity is less than 60% and the indoor temperature is 21°C, the moisture content within all studied retrofitted typical wall constructions of residential buildings in Istanbul is in an "allowable" range. If indoor relative humidity exceeds 70%, excessive accumulation of moisture occurs on the inner surface or within the retrofitted wall construction.
Keywords: Exterior wall, moisture performance, residential building, retrofitting, water vapor diffusion.

1. Introduction

In Istanbul nearly all residential buildings, built in the seventies and eighties are mainly five or six floors high and have a reinforced concrete skeleton structure. The opaque component of the exterior wall mostly consists of 13.5 cm thick hollow bricks with rendering on both sides and the windows have a wooden frame with single-glazing. During the winter period the insufficient heat resistance of the external envelope causes either insufficient indoor conditions from the point of view of thermal comfort or excessive energy consumption for heating to achieve thermal comfort. since the mid nineties there is an effort, encouraged by the municipality of Istanbul, to retrofit existing buildings to achieve energy saving, reduction of air pollutants and CO_2 emission. The placement of a thermal insulation either inside or outside of the existing wall is a recommended retrofitting practice. When improving the thermal performance of the wall by adding a thermal insulation layer, the moisture performance of the wall under the new conditions should also be taken into consideration.

As water vapor diffusion trough the opaque component of external walls of buildings nearly always occurs due to water vapor partial pressure differences between the interior and exterior environment this is the main kind of moisture transfer under normal conditions. The different layers resist the moisture transfer due to their different material properties i.e., resistance factors. Moisture is accumulated in front of layers with high resistance factors or extraordinary amount of moisture is captured in the wall due to design or construction failures. As moisture is affecting the physical performance of walls, it can cause important defects. Excessive moisture accumulation in the wall construction decreases the heat resistance of materials and so the indoors thermal comfort is affected. Moisture accumulation on the inner surface of walls causes water stains, peeling paint and mold growth. Mold growth in turn has effects on air quality and user’s health.

The purpose of this paper is to predict the effects of water vapor diffusion on moisture performance of retrofitted typical wall construction using meteorological data for Istanbul and to develop a moisture control guideline using results from those predictions.

2. Calculation method

In the calculation method, for appraising the effects of water vapor diffusion on the thermal and moisture performance of external walls, the hourly and daily fluctuations of outdoor climatic elements, i.e. temperature, relative humidity (RH) and solar radiation as well as the interaction between moisture content and material properties, i.e. thermal conductivity and vapor diffusion resistance factor were considered, [1]. The main features of the calculation method, are as follows :

- A finite difference method.
- Both moisture and temperature distribution; they are calculated transiently.
- The calculations are one - dimensional.
- Transport of moisture is mainly by vapor diffusion, but in the case of when relative humidity exceeds 100% i.e. the moisture content reaches the critical value at any point, moisture transport is by capillary suction due to water absorption properties of the materials.

- Material properties vary with the moisture content.
- Convection transfer of heat and moisture are considered at the boundaries.

Under transient conditions with no internal generation the one-dimensional heat diffusion equation is;

$$\frac{\partial T}{\partial t} = a \cdot \frac{\partial^2 T}{\partial x^2} \qquad (1)$$

For solving equation (2) with the finite difference method, the wall is assumed to be divided into "m" Ax - layers. the temperature ($T_j^{t+\Delta t}$) at any internal node "j" representing a Ax - layer and the surface temperature ($T_1^{t+\Delta t}$) at the new time "t+Δt" are determined with equation (2) and (3) respectively.

$$T_j^{t+\Delta t} = a \cdot \frac{\Delta t}{\Delta x^2} \quad [illegible] \quad 1 - \frac{2 \cdot a \cdot \Delta t}{\Delta x^2}) \cdot T_j \qquad (2)$$

$$T_1^{t+\Delta t} = \frac{2 \cdot \alpha_o \cdot \Delta t}{\gamma \cdot c \cdot \Delta x} \cdot (T_e - T_1) + 2 \cdot a \cdot \frac{\Delta t}{\Delta x^2} \cdot (T_2 - T_1) + T_1 \qquad (3)$$

where,

a	: [m²/s]	Thermal diffusivity
α_o	:[W/m²°C]	Convection heat transfer coefficient, outside
γ	: [kg/m³]	Density
c	:[j/kg °C]	Specific heat
T_e	:[°C]	Sol -air Temperature

The moisture distribution in the wall is determined as offered in [2]. Under the assumption that during the time interval "At" the conditions (T, φ, P) at any Ax -layer and the environment are constant the quasi - steady state moisture mass flux due to water vapor partial pressure differences is:

$$m = \delta \cdot \frac{\Delta P \cdot \Delta t}{\mu(\varphi) \, . \, \Delta x} \qquad (4)$$

where,

m	: [kg/m²]	Moisture flux
δ	: [kg/mhPa]	Water vapor permeability
AP	:[Pa]	Water vapor partial pressure difference
$\mu(\varphi)$	:[-]	Water vapor resistance factor depending on RH

The water vapor resistance factor depending on the relative humidity is described as follows;

$$\mu(\varphi) \, . \, \mu_0 - (\mu_0 - \mu_{100}) \, . \, \varphi^b \qquad (5)$$

where,

μ_0	:C-]	Water vapor resistance factor (φ=0%)
μ_{100}	:[-]	Water vapor resistance factor (φ=100%)
b	:[-]	Exponent
φ	:[%]	Relative humidity

The equation for the sorption isotherm curves, giving the relation between moisture content and RH is;

$$u(\varphi) = u_0 - \ln(1-\varphi)/d \qquad (6)$$

where,

$u(\varphi)$	:[%/%]	Moisture content depending on RH, vol.
u_0	:[%/%]	Moisture content (φ=0%), vol.
d	:[-]	Bending factor for the sorption isotherm curve

For each node representing a Ax - layer the moisture content at the new time "Δt+t", is the difference between the incoming and outgoing diffusion flux during the time interval "At" added to the moisture content at the previous time "t".

At each time step "At" the thermal conductivity for each material is determined depending on the average moisture content with equations as given in [3]. To achieve realistic results the values of the time interval At and layer thickness Ax are important. In this study; At = 7.2 seconds and Ax = 0.5 cm. For the calculations a computer program written in FORTRAN language is used.

3. Environmental conditions

The driving force for water vapor diffusion in an external wall construction is the water vapor partial pressure difference between the interior and exterior environment. As the water vapor partial pressure is depending on the value of temperature and relative humidity, they are the most important climatic elements for the assessment of the moisture performance of the wall. Solar radiation which is effective on the exterior surface temperature of a wall is also considered for the assessment.

At the meteorological station in Istanbul-Goztepe (lat. : 41°N, long.: 29°E), the outdoor temperature and solar radiation on a horizontal surface are recorded hourly, where as the relative humidity is recorded at 7.00, 14.00 and 21.00. The monthly average values for each hour of those outdoor climatic elements are used for the calculations.

In Istanbul, from November to March heating is needed. In this period, vapor diffusion is mainly from inside to the outside. The year with the lowest main outdoor vapor partial pressure at 7.00, 14.00 and 21 .OO for each of those months are selected from the meteorological records for the years 198 I-1990. This gives the most disadvantageous situation in terms of moisture performance under realistic outdoor environmental conditions. Because of the lowest average outdoor vapor partial pressure in the period when heating is needed February is the most critical month in Istanbul.

The equation of the idealized curve for the periodic fluctuating climatic elements, i.e. outdoor temperature and relative humidity is obtained with the "harmonic analyze" method.

The indoor temperature is considered to be constant at 21°C. The indoor relative humidity is taken from 50% to 80%, with a 10% increment, to show the effects of indoor environment on the intensity of water vapor diffusion and moisture performance of the wall.

Wind speed, affecting the thermal convection at both surfaces is considered to be at constant values inside and outside and so the values of the convection heat transfer coefficient, outside and inside are respectively; α_o = 23.26 W/m²°C, α_i = 8.34 W/m²°C.

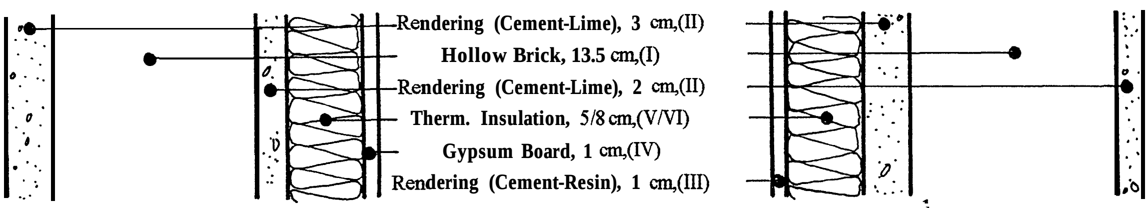
4. Wall construction and material properties

The typical opaque component of a exterior wall construction for residential buildings in Istanbul consists of a **13.5** cm thick hollow burned clay brick with mineral rendering on both sides. A recent research has shown that adding a 5 to **8** cm thick thermal insulation, with the thermal conductivity of λ=0.04 W/m°C, to that existing opaque wall component is the most efficient retrofitting practice, from the point of view of energy and cost efficiency, [4]. It is recommended to apply the thermal insulation on the outer surface of the wall if the whole building is retrofitted and on the inner surface of the wall if only some flats of the building are retrofitted.

The walls examined in this study are the typical wall construction described above with a thermal insulation layer added either inside or outside of the wall. As the intensity of the water vapor diffusion is depending on the water vapor diffusion resistance factor and thickness of the insulation layer; a mineral fiber (glass fiber) with a relatively “low” water vapor diffusion resistance factor and a cellular plastic (EPS) with a relatively “high” resistance are the selected materials to use for retrofitting. Also the thickness of thermal insulation layer is alternatively taken as 5 cm or **8** cm. The absorption coefficient of the exterior surface of the wall construction is considered to be a'=0.7 for all alternatives. Also all alternatives are north facing walls. The material properties of the wall layers, which are used in the calculations are given in Table 1. The sections of the typical wall constructions with the inside or outside thermal insulation layer for retrofitting are in Fig. 1.

	HOLLOW BRICK I	RENDERING (CEMENT-LIME) II	RENDERING (CEMENT-RESIN) III	GYPSUM PLASTER BOARD Iv	GLASS FIBER V	POLY STYRENE (EPS) VI
DENSITY, γ, [kg/m3 1	900	1800	**1000**	900	50	**15**
THERM. COND. (DRY), λ_{dry}, [W/m°C]	0.36	0.62	0.50	0.17	0.036	0.034
SPECIFIC HEAT, c, [J./kg°C]	920	**1050**	**1050**	840	840	1210
WATER ABSORE'. COEF., w, [kg/m$^2\sqrt{h}$]	8	3	0.4	70	**0.01**	**0.01**
MOISTURE CONTENT $u_0(\varphi=\%0)/u_{cr}(\varphi=\%100)$, [-]	0.001/ 0.25	0.01/ 0.12	0.0/ **0.1**	0.001/ 0.35	0.004/ **0.1**	0.0/ **0.1**
VAPOR DIFF. RES. FACT. $\mu_0(\varphi=\%0)/\mu_{100}(\varphi=\%100)$, [-]	6/2	18/4	11/9	1313	1/0.99	20/5

Table 1. The material properties of the wall layers.



a b

Figure 1. Retrofitted wall constructions studied (a: thermal insulation applied on the inner surface, b: thermal insulation applied on the outer surface).

5. Results

The moisture distribution at the surfaces and within the wall construction is an important criterion for the assessment of the moisture performance of the wall. The moisture distribution can be expressed either in moisture content or relative humidity. As the moisture content levels of various materials in a wall construction differ from each other it is not easy to show them on a graph at the same scale. To achieve graphical continuity in showing the moisture distribution within the wall construction, the relative humidity was preferred.

The moisture distribution, expressed in relative humidity (RH), within the existing wall constructions retrofitted either inside or outside with a mineral fiber or cellular plastic thermal insulation for the end of the month February are given in Fig. 2 to Fig. 5.

5 cm thermal insulation applied on the outer surface of the wall (Fig. 2):

When a glass fiber or polystyrene (EPS) thermal insulation is used for retrofitting and an indoor RH of SO%, the highest RH, for both alternatives, occurs as 100% on the inner surface of the wall that indicates surface condensation. Within the glass fiber layer the RH increases from 65% to 70% from the inside to outside. Whereas within the polystyrene layer the RH decreases from 80% to 65% from the inside to outside

5 cm thermal insulation applied on the inner surface of the wall (Fig. 3):

When a glass fiber thermal insulation is used for retrofitting and an indoor RH of 80%, the highest RH occurs as 95% in the wall section between the outer surface of the thermal insulation and rendering. Within the glass fiber layer the RH increases from 85% to 95% from the inside to outside. When a polystyrene (EPS) thermal insulation is used for retrofitting and an indoor RH of 80% the highest RH is 85% in the wall section between the outer surface of the gypsum board and thermal insulation. Within the polystyrene layer the RH decreases from 85% to 75% from the inside to outside.

8 cm thermal insulation applied on the outer surface of the wall (Fig. 4):

When a glass fiber thermal or polystyrene (EPS) insulation is used for retrofitting and a indoor RH of 80% the highest RH, for both alternatives, occurs as 100% on the inner surface of the wall that indicates surface condensation. Within the glass fiber layer the RH increases from 65% to 70% from the inside to outside. Whereas within the polystyrene layer the RH decreases from 80% to 65% from the inside to outside.

8 cm thermal insulation applied on the inner surface of the wall (Fig. 5):

When a glass fiber thermal insulation is used for retrofitting and an indoor RH of 80%, the highest RH is 100% in the wall section between the outer surface of the thermal insulation and rendering. Within the glass fiber layer the RH increases from 85% to 100% from the inside to outside. When a polystyrene (EPS) thermal insulation is used for retrofitting and an indoor RH of 80% the highest RH is 85% in the section between the outer surface of the gypsum board and thermal insulation. Within the polystyrene layer the RH decreases from 85% to 70% from the inside to outside.

6. Conclusion

The results show that the vapor diffuses relatively “easy” through the layers with a “low” water vapor diffusion resistance factor, like the mineral fiber thermal insulation, and it is accumulated in front of layers with a relatively “high” resistance, like mineral rendering. If the thermal insulation system is applied on the outer surface of the wall, the mean RH

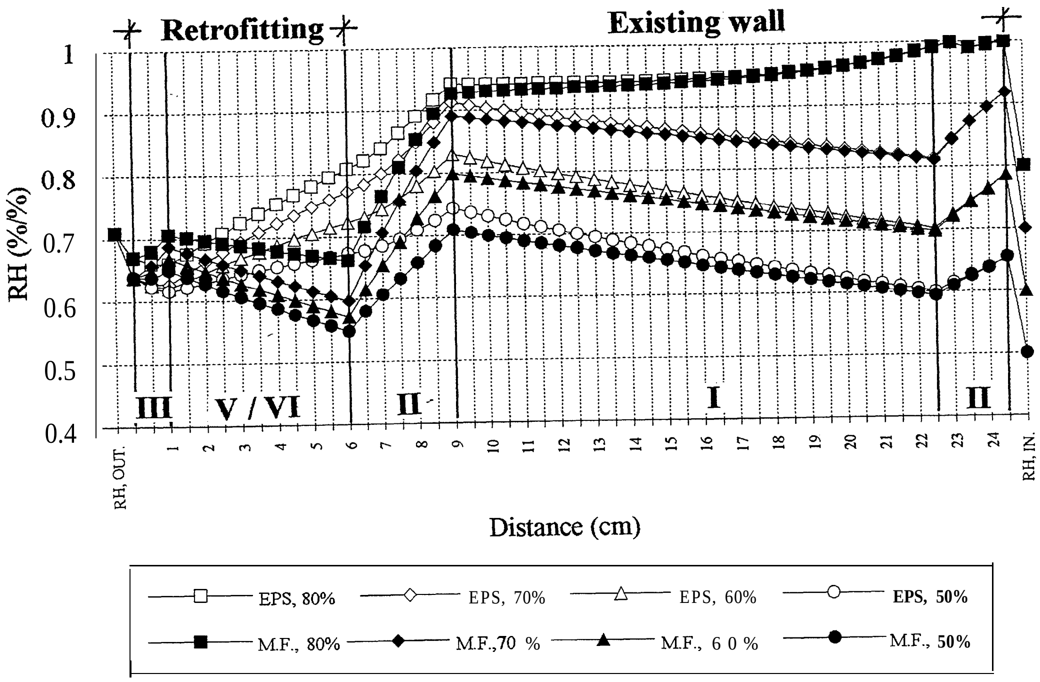


Figure 2. RH distribution in a wall retrofitted with a 5 cm thermal insulation (polystyrene:EPS or glass fiber : M.F.) applied at the outside surface with indoor RH of 50%, 60%, 70% or SO%, at the end of February, in Istanbul.

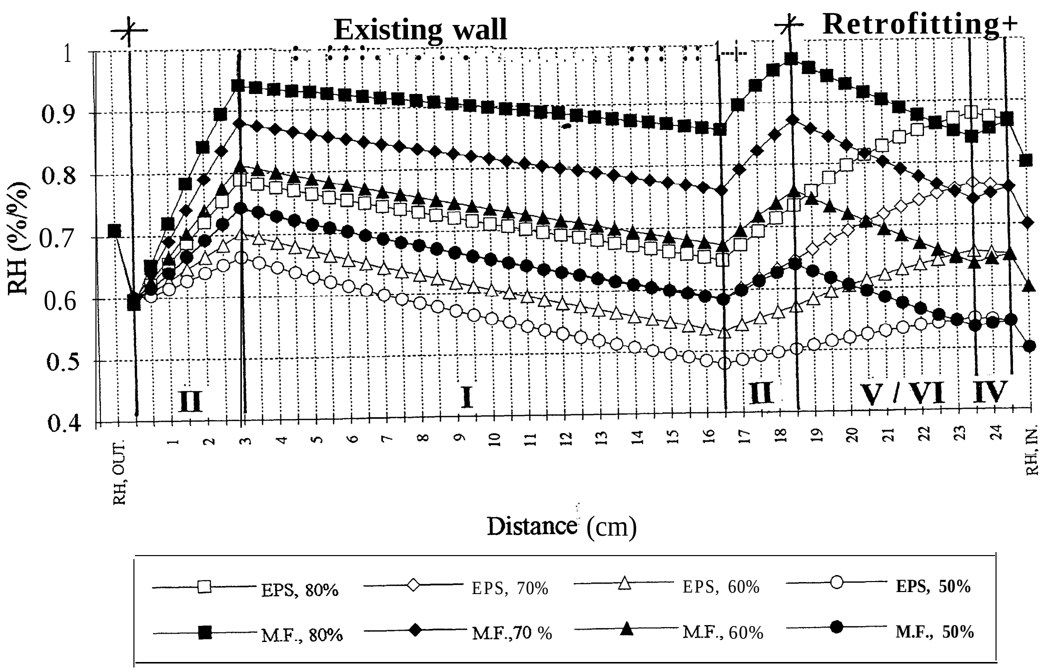


Figure 3. RH distribution in a wall retrofitted with a 5 cm thermal insulation (polystyrene:EPS or glass fiber : M.F.) applied at the inside surface with indoor RH of 50%, 60%, 70% or 80%, at the end of February, in Istanbul.

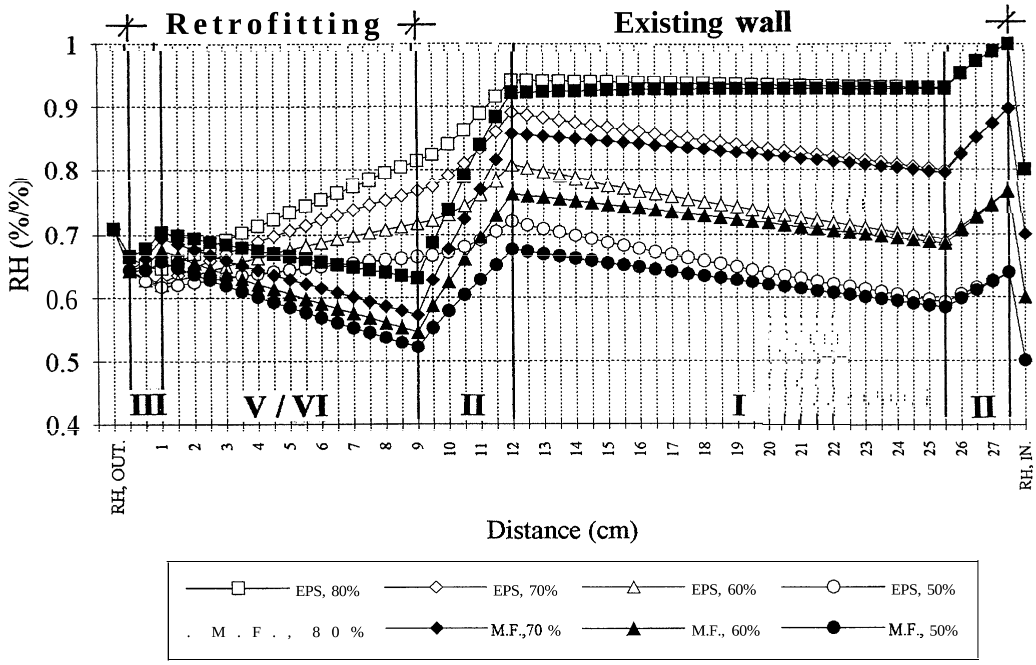


Figure 4. RH distribution in a wall retrofitted with a 8 cm thermal insulation (polystyrene : EPS or glass fiber : M.F.) applied at the outside surface with indoor RH of 50%, 60%, 70% or 80%, at the end of February, in Istanbul.

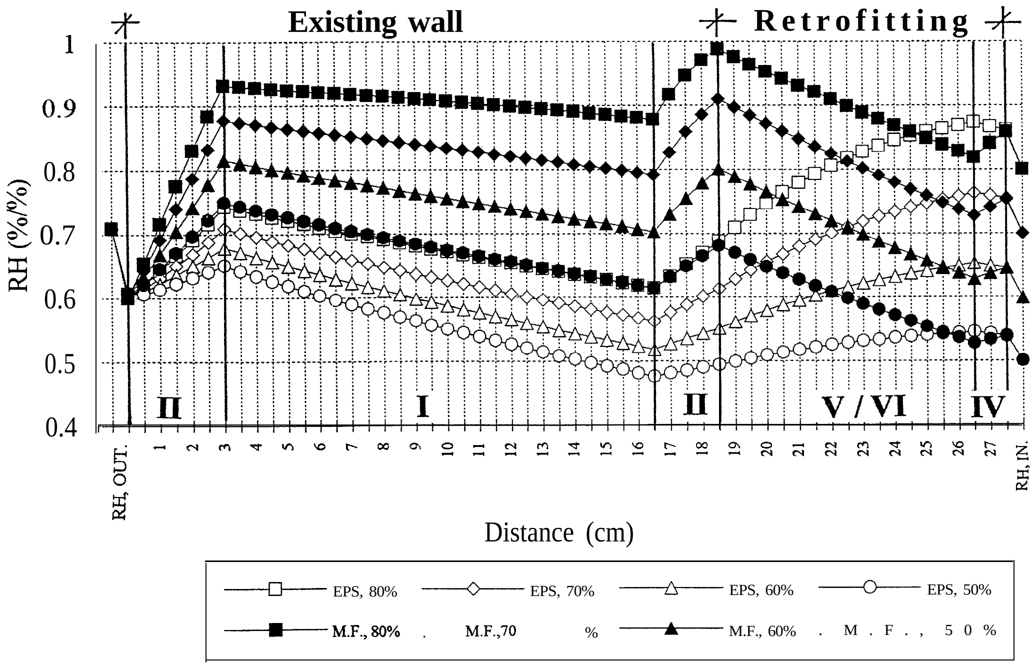


Figure 5. RH distribution in a wall retrofitted with a 8 cm thermal insulation (polystyrene : EPS or glass fiber : M.F.) applied at the inside surface with indoor RH of 50%, 60%, 70% or 80%, at the end of February, in Istanbul.

within the cellular plastic thermal insulation is higher than the mean RH within the mineral fiber material under the same indoor environmental conditions. If the thermal insulation system is applied on the inner surface of the wall the mean RH within the mineral fiber thermal insulation is higher than the mean RH within the cellular plastic material under the same indoor environmental conditions. So the increasing of the thermal conductivity value for cellular plastic thermal insulation applied on the outside of the wall and of mineral fiber thermal insulation applied on the inside of the wall is higher than the other alternatives, according to the higher amount of moisture.

When the indoor mean relative humidity is less than *60%* and the indoor temperature is 21°C, the moisture distribution within all studied retrofitted typical wall constructions of residential buildings in Istanbul is in the range of 80% to 50%, at the end of February. This amount of moisture can be considered as "allowable", thus it is not necessary to take any preventive measures during retrofitting. The same conditions appear also for retrofitting with 5 to 8 cm cellular plastic thermal insulation (EPS) applied on the inner surface of the wall when the indoor RH is less than 70%.

When the indoor RH is higher than 70%, the RH within the wall or on its inner surface is between 60% to 100%, for all examined retrofitting alternatives, except for the EPS insulation placed on the inner surface. To avoid internal or surface condensation in this period of the year some measures has to be taken. Either proper ventilation should be done to decrease indoor RH in both alternatives for the placement of the thermal insulation or a vapor retarder should be placed on the inner side of the wall for thermal insulation applied on the inner surface. The vapor retarders diffusion resistance should be at a level to retain diffusion, but not to cause excessive accumulation on its "inner" surface.

In designing a typical wall construction for retrofitting of residential buildings in Istanbul, the following points should be taken into consideration:

- If any kind of thermal insulation system is applied on the outer surface of the wall the indoor mean relative humidity should be less than 70% during the heating period, to avoid surface condensation.
- If 5 to 8 cm thick mineral fiber thermal insulation is applied on the inner surface of the wall the indoor mean relative humidity should be less than 80% during the heating period, to avoid condensation within the wall.

References

1. *ALTUN*, MC. (1996) *An Approach for Appraising the Effects of Water Vapor Diffusion on the Thermal and Moisture Performance of Exterior Walls*, Ph.D. Thesis (in Turkish), İ.T.Ü. Fen Bilimleri Enstitüsü, Istanbul.
2. RICKEN, D. (1991) Ein Einfaches Berechnungsverfahren für die Instationäre Wasserdampfdiffusion, *Bauphysik* 13, Heft 2/91, pp.33 - 37.
3. ACHTZIGER, *J.* , *CAMMERER*, J. (1984) *Einfluß des Feuchtegehalts auf die Wärmeleitfähigkeit von Bau- und Dämmstoffen*, IRB - Verlag der Fraunhofer Gesellschaft, Stuttgart.
4. ÖZKAN, E. , *ALTUN*, M.C. , TAVİL, A. , ŞAHAL, A.N. (1997) *Developing Energy Efficient External Envelope by Retrofitting in Rehabilitation of Existing Residential Buildings*, TÜBİTAK - INTAG / TOKİ 223, Research Project, Final Report (in Turkish), Istanbul.

The effects of fenestration characteristics on the thermal performance of retrofitted residential buildings in Istanbul

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Abstract

A research project is set to investigate the thermal performance of the external envelope of existing residential buildings in Istanbul and to develop energy efficient systems for retrofitting external envelope of these residential buildings. In this context performance of the existing and the retrofitted windows are also analyzed. DOE-2.1E energy analysis simulation program is used for the simulation of heat loss and gain through the external envelope by modeling the buildings with their near environment, occupant, lighting and equipment schedules.

The annual energy performance of a window is not dependent on its instantaneous thermal and optical characteristics alone. In fact, it is strongly dependent on a large number of variables related to the total fenestration system. In evaluating the energy efficient rehabilitation of residential buildings, varying fenestration characteristics are effective on the total thermal performance of the buildings right along with the thermal insulation in the opaque components of the building envelope.

In this study, energy analysis of a retrofitted existing typical residential building in Istanbul will be presented and the effect of the variations in fenestration characteristics on the thermal performance of these buildings will be evaluated. In this analysis, fenestration variables which affect the thermal performance of the retrofitted residential buildings are considered in three main groups:

- Properties of the frame and glazing system.
- Orientation and shape of the building which is effective with the climatic variables.
- Optical properties of the window, shading devices and the user attitude for the management of the shading devices.

The effect of these variables on the annual heat loss of a residential building will be discussed with varying fenestration systems generally used in high story residential buildings in Istanbul. Finally, the thermal performance of the retrofitted external envelopes were studied for the evaluation of heating energy savings while sufficient thermal comfort in residential buildings was succeeded.

Keywords: Computer simulation, energy analysis, fenestration characteristics, residential building, retrofitting, thermal performance.

1 Introduction

A research project has been carried out to investigate the thermal performance of the external envelope of existing residential buildings in Istanbul and to develop alternative envelope systems for energy efficient retrofitting of these buildings, [1]. The study also covers to understand the effects arising from variation in the fenestration properties as types, sizes and shading of windows, infiltration, natural ventilation level and orientation of buildings. An appropriate range was selected for each variable to insure coverage of the expected variation typical in the multistory residential buildings in Istanbul.

A PC version of DOE-2.1E computer program., which is comprehensive enough for the energy simulation, has been used to analyze the thermal performance of residential buildings. Basically, two groups of data files, the weather data file of Istanbul and the building description input file representing the existing typical residential buildings in Istanbul, and the energy efficient alternative insulation and fenestration systems were prepared for the simulation. Finally, the thermal performance of the retrofitted external envelopes were studied for the evaluation of heating energy savings while sufficient thermal comfort in residential buildings was succeeded.

As windows are an important aspect in the design of most buildings, they play an important role in defining a building's aesthetics and occupant considerations of visual and thermal comfort. Windows are also a major factor in design because of their influence on building energy use. In case of residential units, which are heavily envelope dependent, windows strongly influence annual heating and cooling requirements, [2].

The energy performance of a window is not dependent on its instantaneous thermal characteristics alone. In fact, it is strongly dependent on a large number of variables related to the total fenestration system, climate and thermal and geometric characteristics of the building where the window is installed. Therefore, performance of a fenestration system should involve an assessment of these variables and interactions among them.

In recent studies, the effects of building and window orientation, window area, solar shadings, heat transfer (U-value), heating-cooling requirements associated with residential buildings are analyzed, [3, 4]. While the window frame, glazing systems, glass types, and the coatings on the glass such as for Low-E are considered for the assessment of the total U-value. Thus, the performance of a fenestration system is improved, [5].

The change in the solar radiation gain through windows is very effective on thermal performance of windows. A large percentage of windows have an internal and/or external shading or privacy devices such as blinds, drapes, shutters etc. Thus the magnitude of the solar gain also depends on the characteristics of these devices.

In this study, the fenestration variables which affect the thermal performance of the retrofitted residential buildings are analyzed in three main groups:

- Properties of the frame and glazing system.
- Orientation and shape of the building which is effective with the climatic variables.
- Optical properties of the window, shading devices and the user attitude for the management of the shading devices.

2 Description of the environmental variables and the residential building

In this study, an existing residential block representing the typical residential multistory buildings in Istanbul is chosen as a sample building. Istanbul takes place on the latitude of 41 degree north and the sample building faces to north. The built-up area of the sample building is 13*15 m and surrounded with eight residential blocks. They are specified in order to simulate the shading effect of the buildings in the neighborhood.

Hourly weather data of Istanbul, prepared as 'Test Meteorological Year-TMY' file according to the method given in ASHRAE Fundamentals, [6]. It contains one year of hourly data for each weather variable including direct-normal radiation, observed radiation, temperatures, atmospheric pressure, wind speed, sky cover etc.

2.1 Building specifications

Five story sample building having two housing units at each floor is 19.15*13.0 m in size. The total floor area is 1067 m^2 and the total building volume is 2881 m^3. A reinforced concrete structure, exterior non-bearing brick walls, single glazed wooden windows and a pitched roof are the typical elements of this residential block. A 1.5 m overhanging floor open to the outdoor environment surround the four sides of the building on the first floor. There are four balconies with 1.5x4.0 m size at each floor.

2.2 Internal load assumptions

The building is heated with a central heating system., therefore one temperature zone is accepted and the indoor temperature is assumed to be 21 °C. The floor weight with the furniture is taken to be 500 kg/m^2. The equipment load is calculated as 3 W/m^2 according to the sensible heat gain value of 350 W which assume that the cooking range and clothes drier are vented. The lighting type is incandescent and the maximum output is taken as 7 W/m^2 for each housing unit. The average lighting energy figure in a housing unit is assumed to be equivalent to using two 120 W bulb between 17.00- 18.00 hour, four 120 W bulb between 19.00-21.00 hours, two 120 W bulb between 22.00-24.00 hours and no lighting is used between 1.00-16.00 hours. Three people are living at each housing unit where the occupancy load is assumed to be 130 W/person, [6]. The building is totally occupied from 24.00 to 7.00 and 50 % of the resident is staying in from 8.00 to 23.00.

All the opaque components of the existing building are thermally uninsulated. For the retrofitted building, the exterior walls, the exterior overhanging floor and the roof slab are externally insulated with 5 cm expanded polystyrene with thermal conductivity of 0.035 W/mK for simulations. The interior floors are assumed to be adiabatic. This insulation system is determined as an energy efficient system in retrofitting of the existing residential buildings in Istanbul, [7].

3 Simulation

Numerical simulation is the approach used to study the effects of the fenestration characteristics of the sample building. DOE-2.lE Building Energy Simulation Program was selected for the simulation of the thermodynamic behavior of a building, to determine energy consumption and to test the sensitivity of this behavior to the selected building parameters, [8, 9].

Three glazing and four framing systems are considered for performance evaluation. For glazing, 3 mm clear single pane-(Gl), 3/13(air)/3 mm clear double glazing-(G2) and 3/13(air)/3 mm low-e double glazing-(G3) with the U value of 6.3, 2.8 and 1.8 W/m^2K, are used respectively. For framing, aluminum-without thermal break-(Fl), aluminum-with thermal break-(F2), wood-(F3) and vinyl-(F4) frames with thermal conductance of 17.2, 7.05, 2.46 and 1.8 W/m^2K are considered respectively. The transparency ratios are different in each facade. In order to study the effect of building direction on the annual heat loss, the sample building which is oriented to North (Dl), is rotated 45° and 1090°, oriented to North-West (D2) and West (D3).

The effects of varying window shading devices were studied by selecting four different white colored devices (Sl), (S2), (S3), (S4) with shading coefficients (SC) of 0.65, 0.55, 0.4, 0.2 and transmittance values of 0.65, 0.4, 0.2, 0.0, respectively, [5]. The internal shading device (Sl), which is an open weave fabric drapery is used to obtain outward vision and privacy. They are usually kept closed during day and night. The device (S2), which is a semi-open weave fabric drapery is used to control distracting inward view is usually kept closed during day and night time for the privacy. The device (S3), which is a close-weave drapery and (S4) which is an exterior roll blinds are used where protection from radiation is paramount with low SC values. In order to evaluate the effect of user attitude of managing the shading devices on the annual heat loss, four different management schemes are accepted; the shading devices are closed during the day and night (Rl), the shading devices are closed when the transmitted direct radiation exceeds 50 W/m^2 -(R2), 100 W/m^2 -(R3), 150 W/m^2 -(R4).

4 Discussion

In evaluating the effects of fenestration characteristics on the thermal performance of the retrofitted residential building, the annual heat losses for the building which were calculated according to the variables as glazing systems, frame types, shading coefficient, shading management of users and the building orientation are summarized in Table 1.

4.1 The effect of framing materials and glazing types on heat losses

The annual heat loss and the decrease in annual heat loss of the building according to the variation of the types of window framing and glazing are given in Figure 1. The annual heat losses of the building with single pane aluminum frame (without thermal break) window (F1G1) with a total U value 7.5 W/m^2K, and Low-E double glazed vinyl window (F4G3) with a total U value 1.7 W/m^2K are calculated as 142.6 KWh and 93.3 KWh respectively and thus, the maximum reduction in the annual heat loss through the building is realized 34.6 % by improving the window frame and the glazing system.

Considering the window framing materials, the maximum annual heat loss for the building that having windows with double-glazing and aluminum frame-without thermal break-FlG2 is 117.4 KWh. Using aluminum frame-with thermal break, wood frame and vinyl frame decrease the annual heat loss 6.5, 12.7 and 14 % respectively, Figure 1.

The annual heat loss of the building with vinyl framed windows and single glazing-(F4G1), double-glazing-(F4G2) and Low-E double-glazing-(F4G3) are 126 MWh, 101 MWh, 93 MWh, respectively They provide 11.6, 14 and 15 % decrease in annual heat loss when compared with the heat loss of building with aluminum framed and single-glazed windows-(F1G1), Figure 1.

Fenestration Systems	U-value Frame W/m2K	U-value Glass W/m2K	SC	Trans. Rad. W/m2	Orien-tation	Window U-value W/m2K	Window Cond. (-)MWh	Window Solar (+MWh)	Total Heat Loss (-)MWh
F1G1	17.2					7.49	92.39	26.91	**142.55**
F2G1	7.05	6.31	0.65	**0**	North	5.53	84.34	26.65	**134.80**
F3G1	2.46	(G1)	(S1)	(R1)	(D1)	4.64	76.65	26.33	**127.45**
F4G1	1.81					4.52	75.10	26.27	**125.96**
F1G2	17.2					5.40	61.09	20.80	**117.43**
F2G2	7.05	2.79	0.65	**0**	North	3.44	53.13	20.5 1	**109.76**
F3G2	2.46	(G2)	(S1)	(R1)	(D1)	2.56	45.52	20.11	**102.49**
F4G2	1.81					2.43	43.98	20.04	**101.02**
F1G3	17.2					4.71	48.00	15.99	**109.69**
F2G3	7.05	1.81	0.65	**0**	North	2.76	40.06	15.73	**102.02**
F3G3	2.46	(G3)	(S1)	(R1)	(D1)	1.87	32.55	15.41	94.75
F4G3	1.81					1.74	31.03	15.35	93.27
S1R1			0.65				43.98	20.04	**101.02**
S2R1	1.81	2.79	0.55	**0**	North	2.43	44.46	18.97	**102.90**
S3R1	(F4)	(G2)	0.4	(R1)	(D1)		45.12	17.12	**105.84**
S4R1			0.2				46.03	14.34	**109.94**
S1R2			0.65				43.55	21.34	**99.01**
S2R2	1.81	2.79	0.55	50	North	2.43	43.86	20.64	**100.27**
S3R2	(F4)	(G2)	0.4	(R2)	(D1)		44.36	19.57	102.24
S4R2			0.2				· 44.97	17.82	104.99
sm.3			0.65				43.29	21.92	98.01
S2R3	1.81	2.79	0.55	100	North	2.43	43.53	21.41	98.97
S3R3	(F4)	(G2)	0.4	(R3)	(D1)		43.89	20.60	100.45
S4R3			0.2				44.34	19.34	102.52
S1R4			0.65				43.08	22.28	97.30
S2R4	1.81	2.79	0.55	150	North	2.43	43 .28	21.91	98.04
S3R4	(F4)	(G2)	0.4	(R4)	(D1)		43.56	21.35	99.18
S4R4			0.2				43.91	20.41	100.77
SlD2			0.65		North-		43.82	20.29	100.46
S2D2	1.81	2.79	0.55	0	West	2.43	44.36	19.05	102.44
S3D2	(F4)	(G2)	0.4	(R1)	(D2)		45.01	17.12	105.54
S4D2			0.2				46.03	14.25	109.90
S1D3			0.65				43.73	20.63	99.81
S2D3	1.81	2.79	0.55	0	West	2.43	44.23	19.43	**101.87**
S3D3	(F4)	(G2)	0.4	(R1)	(D3)		45.02	17.43	**105.10**
S4D3			0.2				46.07	14.36	**109.65**

Table 1: The calculated heat losses of the fenestration systems

4.2 The effect of orientation

The effect of orientation can be significant on the thermal performance of the building due to the window area and the window shading coefficient. The annual heat loss of the building with double glazed vinyl windows (F4G2) and open weave fabric draperies (S1) which are closed during day and night time for privacy are calculated 101 MWh, 100.5 MWh, 99.8 MWh, for different directions D 1, D2, D3, respectively. The effect of building direction on the annual heat loss is very low as the window areas of the facades are very close to each other and the variation of the building direction seems not to be effective for this situation. However, the variation of building direction would influence the annual heat loss when the transparency ratios of the facades differ.

4.3 The effect of window shading devices and shading management

In considering the solar heat gain through windows, shading devices are significant parameters with their optical properties. The annual heat losses of the sample building, which is oriented to north, having an external envelope insulation with 5 cm cellular boards and with vinyl framed double glazed window are calculated for four different shading devices S1, S2, S3, S4 which have shading coefficients of 0.65, 0.55, 0.40, 0.20, respectively. The annual heat losses of the building with these shading devices are calculated as 101, 103, 106 and 1 10 MWh when the devices are closed. In comparison with the exterior roll blind (S4), shading devices S 1, S2, S3 provides 8.1, 6.4 and 4 % decrease in annual heat loss. This shows that the energy savings increase due to the solar heat gain when the shading coefficient of the shading device increases.

The user attitudes for managing the shading devices are effective in the solar heat gain from the windows while providing privacy. The annual heat losses of the sample building with different shading devices S1, S2, S3, S4 and the way of management are expressed with the transmitted direct normal radiation, Figure 2. When the shading devices are kept closed during the day and night (R=O W/m^2) and kept open until the transmitted direct radiation reach 50, 100 and 150 W/m^2, the annual heat losses of the building with open weave fabric draperies (S 1) calculated as 10 1, 99, 98 and 97 MWh, while the heat losses of the building with exterior roll blinds (S4), are calculated as 110, 105, 103 and 101 MWh, respectively. By managing the shading devices due to the transmitted radiation, the decreases in heat loss are 2.0, 3.0 and 3.7 % for open weave fabric draperies and 4.5, 6.8, and 8.3 % for exterior roll blinds.

5 Concluding remarks

The results of the computer simulation analysis shows that the characteristics of window framing and glazing systems, and the optical properties and user management of shading devices can significantly reduce the annual heat loss of the residential building.

- The maximum reduction in the heat loss of the insulated building envelope, 34.6 %, is succeeded when the single pane aluminum framed window is replaced with Low-E double glazed vinyl framed window.
- Considering the double glazed window, if aluminum frame-without thermal break replaced with wood or vinyl frame, the annual heat loss decreases 13 and 14 %.

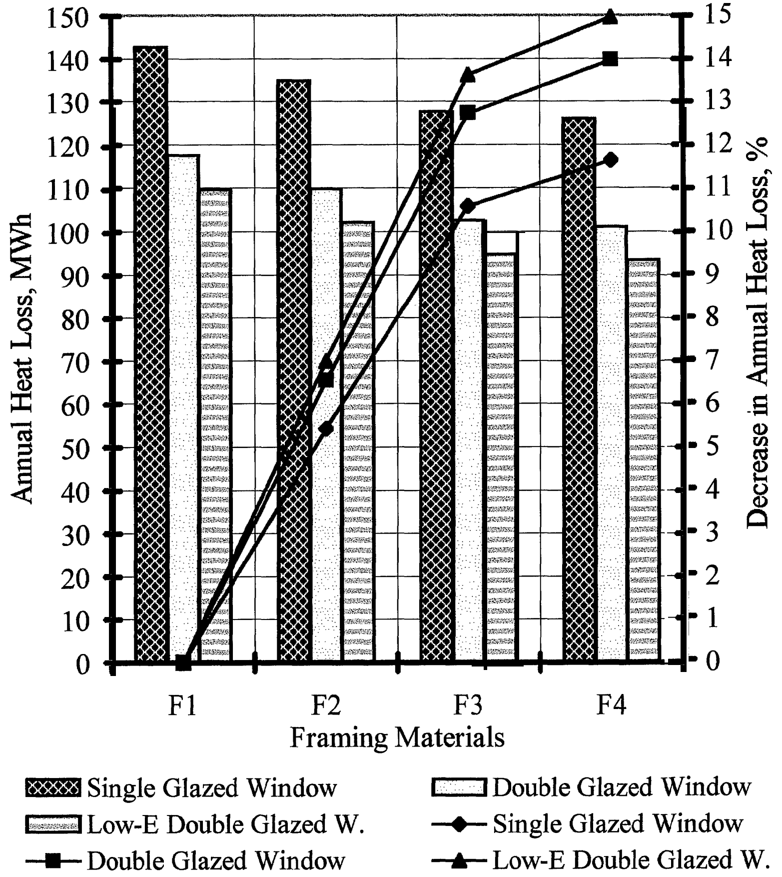

Figure 1: Effects of the window glazing and framing systems on the annual heat loss and decrease in building heat loss in percentage according to glazing systems

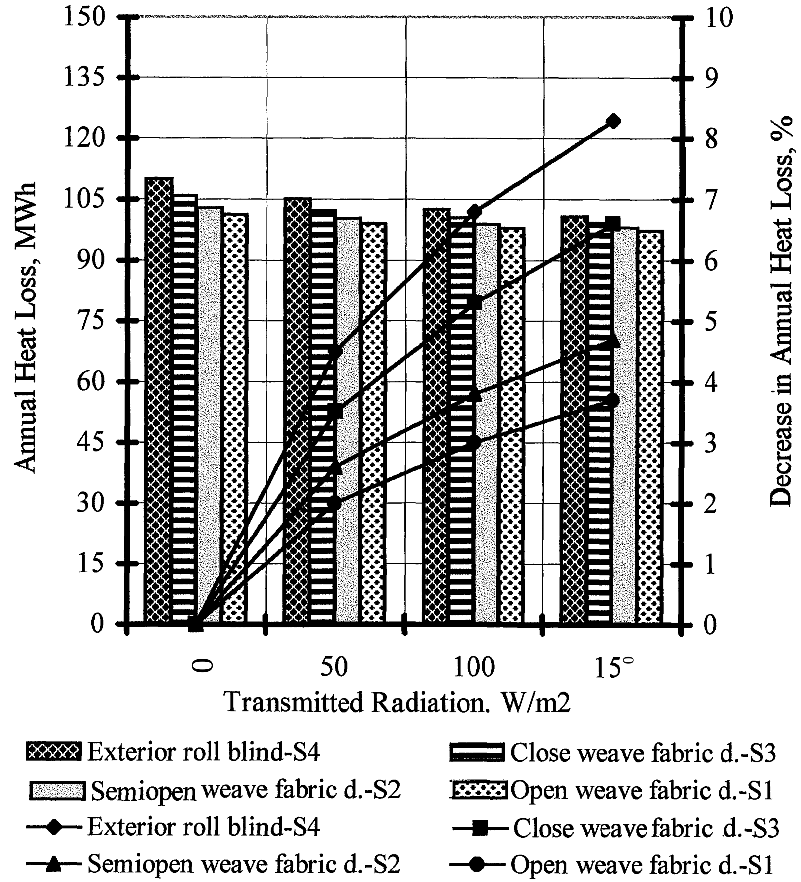

Figure 2: The effects of shading devices and management on the heat loss and the decrease in heat loss due to the transmitted radiation

- In comparison with the exterior roll blind with SC of 0.2, an open weave fabric drapery with SC of 0.65 as the internal shading device provides about 8 % decrease in annual heat loss. This shows that increase in the solar radiation gain due to increase in the shading coefficient increases the energy savings.
- By managing the shading devices according to the transmitted radiation that reaches 150 W/m^2, the decreases in heat loss are 3.7 % for open weave fabric draperies and 8.3 % for exterior roll blinds.

The fenestration system with the influence of these variables should be taken into consideration while designing the retrofitting of existing building fenestration system to control the thermal performance of the existing residential buildings.

6 Acknowledgments

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7 References

1. E.Ozkan, C.Altun, A.Tavil, N.Sahal (1997) *Developing Energy Efficient External Envelope by Retrofitting in Rehabilitation of Existing Residential Buildings,* The Scientific and Technical Research Council of Turkey, Construction Technologies Research Grant Committee, Project Number-TUBITAK, INTAG/TOKI 223, Final Report, Istanbul.
2. *Sullivan,* R., Selkowitz, *S.* (1987) *Residential Heating and Cooling Energy Cost Implications Associated with Window Type,* ASHRAE Transactions, Vo1.93, Part 1
3. Gueymard, *C.* (1995) *Annual Energy Performance of Residential Advanced Windows Related to Climate, Window Area, and Orientation,* Professional Paper, FSEC-PF-271-95, Florida Solar Energy Center, Florida.
4. Kusuda, T. (1978) *Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies,* National Bureau of Standards Building Science Series 109, Washington.
5. Building Technologies Program., *1994 Annual Report,* Energy and Environment Division, Lawrence Berkeley Laboratory.
6. *ASHRAE Handbook of Fundamentals* (1993), ASHRAE, Atlanta, USA.
7. Sahal N., Ozkan E. (1998), Cost *Efficiency and Financial Feasibility of Retrofitting with Heat Insulation of Existing Building in Istanbul,* Proceedings of CIB World Building Congress, Gavle, Sweden,.
8. *DOE 2 Reference Manual, Version 2.1 D, Part 1; 1981; DOE 2 Reference Manual, Version 2. I, Part 2, 1980; DOE 2 Sample Run Book, Version 2.1.E, 1993; DOE 2 Supplement, Version* 2. *1 E,* Lawrence Berkeley Laboratory, California, 1993.
9. A.Tavil, N.Sahal, E.Ozkan, (1996) *The Simulations of the Thermal Performance of Retrofitted Existing Residential Buildings in Istanbul with DOE-2.lE Computer Program,* Building Simulation 97, Fifth International IBPSA Conference, Proceedings, Vo1.2, Page: 363-371, Prague.

Indoor Environment and Sustainable Development: A Crucial '*Buildings Partnership*'

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Abstract

Compatibility of the indoor environment and sustainable development is not the issue! Not only is clear potential for compatibility evident between the indoor environment and sustainable development, this compatibility is not a matter of choice, it is a **sine qua non!**

Sustainable developmentfor ***buildings*** should be so defined that a quality indoor environment is a primary component. Moreover, sustainable development should not be considered as attained unless the quality of the indoor environment in buildings meets commonly accepted standards.

It is an undisputed fact that indoor environment quality in many countries has declined precipitously, even as the outdoor environment has improved due to stringent air emission standards. In the US, for example, as many as half of all buildings are estimated to have significant indoor environment problems; the US EPA further estimates that the indoor environment may be as much as ten times more contaminated than its outdoor counterpart. The statistics over the past 25 years paint a dramatic contrast. While gross domestic product increased by 99 percent in the US, emissions of the six leading air pollutants declined by almost 30 percent. In effect, the environmental problem shifted from the outside to the indoor environment.

How do we continue to improve our outdoor environment (also important) while, at the same time, we energetically focus on reversing the decline in our typical indoor environment? The tools for doing this are available, in the form of innovative technologies that destroy varied pathogens while removing a broad range of particulates and odor molecules.

Sustainable development and indoor environment are thus made compatible when the essential interactive relationships between innovative construction materials/methods, air distribution, appropriate mitigation technologies and our health, productivity and general well-being are recognized and implemented in buildings of all types.
Keywords: Indoor air quality, Indoor environment, air cleaning technologies

1. Introduction

What constitutes the largest single component in a building, whether new or old? Depends, you say, upon the type of structure. Not so. The answer is quite simply always the same, no matter what the structure components may be, or how old.

The largest single component of any building is, frankly, the indoor air it contains. This is- true today, and has been so for millennia, with the Pyramids perhaps the notable exceptions (but then, they were not designed for the living). Paradoxically, while the design and construction of buildings, from individual homes to the largest skyscrapers, has improved in almost every aspect over the course of human history, the quality of this most prevalent component has, in the view of many, actually diminished.

According to estimates by the U.S. Occupational Safety and Health Administration (OSHA) and the World Health Organization (WHO), nearly 50% of all buildings in the U.S. including homes, schools, offices, public buildings, etc. have serious indoor air quality problems [1]. The U.S. Environmental Protection Agency (EPA) states that today's buildings typically contain 2 to 5 times the pollutant levels of outside air [2]. Many energy efficient buildings are clogged with stale, polluted air, to include dust, mold, pollen, chemical pollutants, viruses, bacteria, odors and other harmful substances. Studies have shown that indoor air is up to 70 times more polluted than outside air [3]. These toxic air pollutants cause many physical and emotional symptoms; Dr. Jan Stolwijk of the World Health Organization recently stated that, "there is probably more damage done to human health by indoor air pollution than by outdoor pollution." [4]

This trend is occurring at a time when outdoor quality in many countries is improving as more stringent emissions standards reduce the levels of air pollution. In the U.S., for example, the past 25 years have seen a welcome reduction in emissions (29%) while gross domestic product rose by 99% [5]. Similar or better results have been achieved elsewhere.

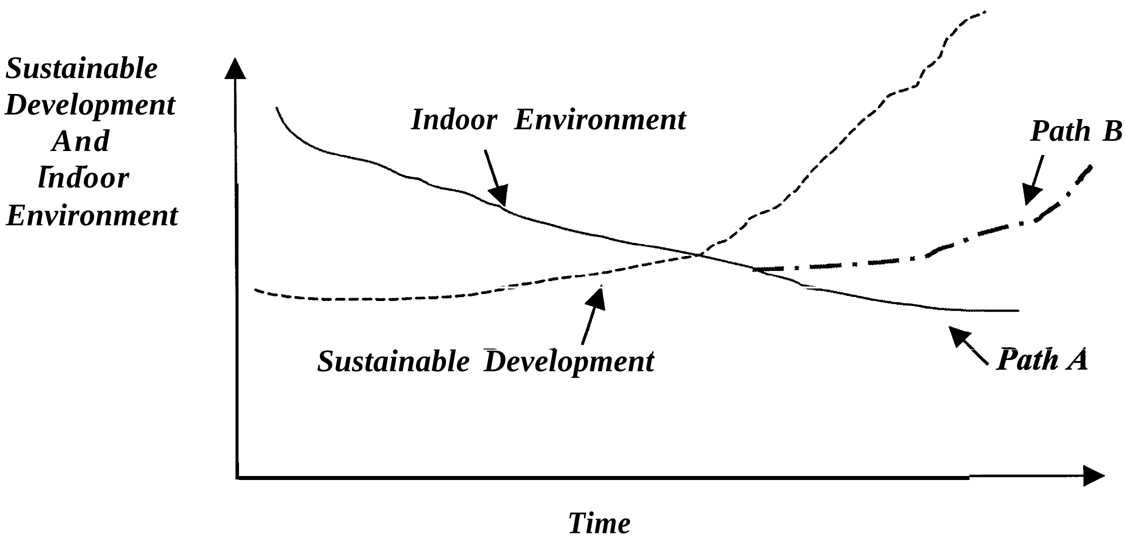
The causes of these countervailing trends are the stimulants for significant scientific research around the globe, by both public and private researchers. *The International Society of Indoor Air Quality and Climate* is surely representative of the many dedicated and excellent scientists and practitioners whose focus is the creation of indoor air quality that meets agreed upon health, comfort and productivity objectives. Among its stated objectives are to [6]:

- Advance the science and technology of indoor air quality and climate as it relates to indoor design, construction, operation and maintenance, air quality measurement and health sciences, and
- Facilitate international and interdisciplinary communication and information exchange

Our objectives today, through this paper, are somewhat different, perhaps not even truly scientific! Thus, we:

- Agree that both indoor air quality (IAQ) and sustainable development are even more vital today than in the past;
- Support the themes for improvement noted for this *CIB World Building Congress* as valid, important and musts for continued scientific perusal, but;
- Suggest that, in the meantime, *much can be accomplished with existing technologies* that is compatible with both sustainable development and the indoor environment! And, perhaps most ardently, we;
- Posit that the indoor environment and sustainable development must be viewed as inseparable and integral components of today's (and tomorrows) "building's focus."

A simple graphic gives a visual dimension to these points. The deterioration of the indoor environment need not occur as suggested by path A; rather, compatible and doable actions will enable simultaneous achievement of objectives related to sustainable development and the indoor environment (path B.)



Sustainable Development and the Indoor Environment- Mutually Exclusive?

"Sustainable Development" remains an elusive term, bending to a number of preferred definitions. Perhaps the most inclusive view, posited by the World Commission on Environment and Development, suggests that sustainable development is *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* [7]

For the construction industry, sustainable development is likewise an elusive concept, with varied defmitions. The 1996 definition that emerged from the Civil Engineering Research Foundation's *International Research Symposium: Engineering and Construction for Sustainable Development in the 21st Century* provides perhaps the most globally accepted and inclusive civil engineering perspective of sustainable development, namely:

> *Sustainable development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter and effective waste management, while conserving and protecting environmental quality and the natural resource base for future development* [8]

How do such global definitions challenge the indoor environment? What is there in the research and development of sustainable building components and practices that threatens the indoor environment? Is there, in fact, a fundamental clash?

Perhaps, at first glance. For example, the need to reduce building energy demand has resulted in the development of varied, innovative materials that effectively seal the building envelope, in effect, reducing the hitherto often significant exchange of indoor and outdoor air. Traditionally, building engineers relied on air changes up to 50% of building air per one-hour period [9]. A significant issue arises as a consequence of this improved "seal," namely chemical contaminants from varied indoor sources, including construction materials. Add to this the possible introduction of external air laden with chemical contaminants, such as automobile emissions and biological contaminants (pollen, viruses, bacteria, spores, etc.) from varied sources and the making of a chemical/biological cocktail becomes reality.

But, do the above examples represent an impasse or merely challenges that require closer coordination and improved understanding of the complex interactions that are inherent in building design, construction, furnishings, operations and maintenance? We argue the latter! Thus, there is no basis, in our view, for the premise that sustainable development and the indoor environment are incompatible. Our basis for this assertion encompasses, instead, continued research and development of mitigating technologies/procedures and common sense approaches that utilize what is now available to mitigate indoor air pollution and thus provide the required and desired indoor environment.

2. The Indoor Environment (IAQ) Problem

How serious is today's indoor environment degradation? There are really two dimensions to this question. We can define the first as the recognized impact of degraded indoor air quality while the second is more elusive and encompasses health and comfort effects that are not immediately obvious. Both are important since the majority of the world's people spend between seventy and ninety percent of their lives in the indoor environment.

In the first category are those impacts generally labeled as either "sick building syndrome" (SBS) or "building related syndrome" (BRI). Both are recognized as significant, with perhaps nearly one-third of all constructed buildings, worldwide, being impacted by SBS/BRI according to the World Health Organization [10].

The causes of SBS are typically labeled as "unknown" while the impacts are anything but! These include dizziness or nausea, headaches, eye, nose and/or throat irritation, skin disorders, fatigue, loss of concentration, etc. Of significance, the symptoms are confined to the structure and relief occurs after leaving the building.

BRI involves identifiable causes, attributable to airborne indoor contaminants. Unlike SBS, the relief/recovery may not occur upon leaving the premises. Again, symptoms may include coughs, fever, chills and muscle aches.

The second category, in our opinion, involves the more elusive concept of optimality. In other words, ***what are the optimal "operational conditions"*** in a building in which the indoor environment is optimized? Is it possible to quantify the optimal health, comfort or productivity associated with such a structure? We do not propose to answer this, merely to suggest in concrete terms, later in this paper, that steps towards optimality are possible.

Finally, we must acknowledge the difficulty in separation of complaints that actually derive from other sources such as allergies, job-related stress, allergies and other psychosocial factors. These clearly may create impacts that in no way should be associated with the building itself.

3. Indoor Environment Solutions

The answer to indoor environment improvement is obvious; remove the cause(s) or source(s)! The difficulty comes in determining "what" and "how."

A traditional response is to increase ventilation rates. This solution, however, has several dis-advantages. First, it is counter to the need for energy efficient solutions. Ventilation carries the penalty of moving large amounts of air at significant energy usage. Secondly, rather than eliminate pollutants, these are simply transferred to the outside environment for possible transfer into other buildings. Thirdly, the higher velocity associated with such increased ventilation rates may, itself, contribute to increased pickup and distribution of unwanted substances. And, finally, heating and ventilation systems are complex systems, requiring significant maintenance and careful adherence to proper operational procedures. Increasing reliance on this method therefore entails both added energy demand and a proper focus on operation and maintenance.

Another response is to identify and remove pollution sources. This may encompass a variety of sources of volatile organic compounds (VOCs) that may derive from carpets, upholstered furniture, computers and copying equipment, solvents, etc. While laudable, one difficulty with this approach is that it also removes many needed or desired products that may, if eliminated, lower productivity or otherwise impact the function of the building in question.

Another solution is air cleaning! This solution takes many forms, from the typically inexpensive but limited efficacy furnace filters to high performance (HEPA) filters to more capable air cleaning systems that do not rely entirely on filters for air purification.

It is this latter family of air cleaning systems that we believe ensure a high quality indoor environment, ***are available now*** and are fully compatible with sustainable development.

There are four essential tasks required to provide and maintain indoor air quality:

- Fresh air exchange (ventilation);
- Elimination of dust, pathogens, pollutants and other airborne substances;
- Replenishment of oxygen, and;
- Maintaining an appropriate ionic balance.

As already noted, ventilating a building with enough fresh air from the outside to replenish oxygen and maintain ionic balance requires a large amount of heat and electrical energy and may bring additional pollution in with the outside air. Filtering the air removes only some of the airborne particles and increases resistance (pressure drop) which requires more energy. None of these measures addresses the critical issue of maintaining the ionic balance of indoor air.

Ions are charged particles in the air that are formed when enough energy (light, heat or other forces) acts upon a molecule such as oxygen, carbon dioxide, water or nitrogen to force the ejection of an electron. The displaced electron attaches itself to another molecule, thereby creating a negative ion. Although negative and positive ions must exist in balance, it is the negative ion of oxygen that has the greatest effect on human behavior. Remember the feelings you may have experienced near the shore, or by a waterfall or high in the mountains? These are locations where the highest concentrations of oxygen ions are found. Normal ion count in fresh country air is 2,000-4,000 negative ions per cubic centimeter (cm^3) [11] or a space about the size of a cube of sugar. At Yosemite Falls, over 100,000 negative per cm^3 have been recorded. Typical building air contains 300-500 negative ions per cm^3, [12] while the Los Angeles freeways have been measured at levels far below 100 negative ions per cubic centimeter. These negative ions or so-called, “small ions” have only a lifetime of two seconds, in effect, they lose their charge very rapidly. Current technology exists that builds up “medium ions” of up to 60 molecules, known as oxygen “clusters”, with a lifespan averaging 2 1/2 hours [13].

Since at least the 1970’s, medical researchers have recognized the beneficial effects of negative ions on human behavior [14]. Irritation, tension, exhaustion and hyperthyroid response along with depression, anxiety, headaches and decreased physical and mental functions have been shown to be alleviated or totally eliminated by increasing the negative ion count in the air. ‘Negative ions are now known to increase alpha brain waves and enhance brain wave amplitude. This increases the speed with which nerve impulses can travel along the synapses of the brain and the nervous system, which translates into a higher awareness level and a greater sense of personal well being. The high ionic level also kills germs and pathogens in the air, which is an important, discernible health benefit.

4. Current Barriers that stifle Attainment of an Enhanced Indoor Environment

While the case for applying innovative technology to improve indoor air quality is obvious (diminished health costs alone justify the effort,) there are formidable barriers that challenge effective implementation, including:

- "A lowest first-cost" mentality or perspective shared by owners, builders, etc.;
- Disconnection between owners, designers and constructors;
- A lack of clearly demonstrable cost/performance benefits for improved indoor air quality;
- Low profit margins inhibit innovation and risk taking;
- Lack of regulatory mandates or voluntary compliance support
- Absence of insurance or health authority encouragement.

Given the low profit margins of U.S. construction and building maintenance, averaging only 2.5% per the Civil Engineering Research Foundation, [15] it is unlikely that innovative building air quality technology will routinely be specified in the United States. Traditionally, Europe leads the world in voluntary compliance and related technology application. A good example is the recent development of an innovative photo-oxidation process for VOC/HAPs abatement and the bi-polar indoor ionization technology that has been used extensively in many public and private German buildings for decades [16].

5. Conclusions/Recommendations

As we look back on human progress in this century, we have much to be thankful for. Many, albeit not yet the majority, enjoy a standard of living inconceivable a scant one hundred years ago. There is hope that these improvements will, in the years to come, encompass more of humanity. Nonetheless, progress has come at a high cost to our environment, both indoor and external. It is the recognition of this impact that has prompted, indeed mandated, a focus on sustainable development.

Buildings are no exception. Fortunately, thousands of skilled researchers and practitioners around the world not only recognize this need but also have embraced sustainable development in every aspect of building life-cycles.

The indoor environment is an essential component of every building and thus, an essential focus for sustainable development. Fortunately, the indoor environment is truly compatible with sustainable development, and, even more significant, amenable to both immediate solutions and continued research and development of even more effective solutions. As practitioners however, we must not lose sight of the fact that, in the end, the single most prevalent component of buildings, the indoor air, is also our responsibility.

References

1. United States Environmental Protection Agency (1997), Indoor Air Quality Information Clearinghouse, *"Indoor A ir-Basic Facts."*
2. United States Environmental Protection Agency (1998), Indoor Air Quality Internet Home Page, http://www.epa.gov/iaq.
3. Karnstedt, James (1991), "Ions and Consciousness," Whole Self Magazine.
4. United States Environmental Protection Agency, Office of Air and Radiation (1997), *"National Air Pollution Emission Trends, 1900-l* 994," Report #EPA-454/R-95-0 11.
5. United States Environmental Protection Agency Administrator Carol Browner, releasing the 1995 *Air Trends Report*, December 17, 1996.
6. Home Page, www.cyberus.ca/~dsw/ (1998), The International Society of Indoor Air Quality and Climate.
7. World Commission on Environment and Development and Climate (1987), *Our Common Future,* (Oxford: Oxford University Press, 1987)
8. Civil Engineering Research Foundation (1996), Final Report, *"International Research Symposium: Engineering and Construction in the 21st Century."*
9. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Standard #62-1989.
10. United States Environmental Protection Agency (1997), Indoor Air Quality Information Clearinghouse, *"Indoor Air-Basic Facts."*
11. Karnstedt, James (1991), *op. cit.*
12. United States Environmental Protection Agency (1997), Indoor Air Quality Information Clearinghouse, *"Indoor Air-Basic Facts."*
13. Schröder, Werner (1995), *"The Process of Air Purification, A Natural Law,"* Bioclimatic, GmbH., Technical Bulletin, p.2.
14. Human Factors Magazine (198 1), *"The Influence of Negative Air Ions on Human Performance and Mood."*
15. Civil Engineering Research Foundation (1997), *"CONMA T Strategic Assessment Workshop,"* Washington, D.C.

Risk management for sino-foreign joint ventures in the Chinese construction

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Abstract

With the application of competitive tendering methods for the procurement of construction projects, the construction industry in China is developing towards the international procurement practice, and such development has attracted many foreign firms into the construction market through the formation of sino-foreign joint ventures. However, as the national economy system in China is still being reformed from the purely planned economy system to a market-orientated system, there are many obstacles and risks affecting the operation of joint ventures. This paper examines the development of the sino-foreign construction joint ventures in China. It presents the risks to the joint ventures in the procurement practice. Effective procurement strategies for sino-foreign construction joint ventures to manage risks have been studied through the investigation of some case studies.

Key words: China, Competitive Procurement, Construction Market, Joint Venture, Risk, Risk Management

1 Introduction

The competitive procurement practice in the Chinese construction has developed quickly. Before 1984 when tendering system was applied to the industry, there was almost no construction contracts procured through tendering [1]. In 1989, about 47,650 projects used bidding for contracts, which accounted for about 13% of the total construction projects in China [2]. In 1995, the number of project contracts applying bids increased to 34.5% of the total construction projects [3]. The selective tendering is the most popular method used in the industry. The application of competitive tendering methods has brought rapid development of other construction sectors in the construction industry in China, including collective construction firms, rural construction teams and sino-foreign joint ventures. The number of joint ventures has been increasing. The ever-growing Chinese construction market become more open to overseas investors and contractors, and will continue to provide good opportunities to foreign firms. According to its 'Ninth Five-Year Plan for the National Economy and Social Development and the Long-term Development Planning to the Year 2010', the Chinese government will fully establish the socialist market economy system within the future 15 years. Official report indicates that during the ninth 5 year from 1996 to 2000, the total fixed asset investment in China will be US$1560 billion with about 60% for construction works. During this period, the construction area for various new houses will reach 1.4 billion square metres, the investment in municipal public utilities will be up to around US$70 billion, and 4 billion square metres of urban and rural housing will be renovated [4].

However, as the national economy system is still being reformed from purely planned system to market-orientated system, and the marketing mechanism for business is still being established, there are many obstacles and risks affecting the operation of sino-foreign joint ventures. In a typical joint venture, the overseas party is usually responsible for the provision of the majority of finance, and the local partner will normally provide facilities, land, labour, or other assets. The overseas party is in a more risky situation as they could not easily take with them the assets invested if they really find not worth of continuing and want to withdraw. It is important for a joint venture to understand the potential uncertainties to the operation of the venture and to develop proper procurement strategies for managing the risks. Little literature appears to be done in this field. It is the major objective of this paper to study the risks involved in sino-foreign construction joint ventures in China, and to investigate procurement strategies for managing the risks.

2 Development of sino-foreign joint ventures in the Chinese construction

Sino-foreign joint ventures are promoted in China to invest in all economic sectors for attracting foreign capital, advanced technology, and the expertise that can be transferred to the indigenous Chinese partners. There are mainly two types of sino-foreign joint ventures practicing in China.

2.1 Equity joint venture

An equity joint venture is actually an enterprise jointly invested by a Chinese firm and a foreign partner. Both two partners jointly invest and manage the business operations. Normally, profits and losses are shared according to the equity stake, the proportion of which for the foreign partner is usually not less than 25% [5]. Partners' responsibilities and benefits are governed and protected by the 'Law of the People's Republic of China on Joint Ventures Using Chinese and Foreign Investment'. As a limited liability enterprise, an equity joint venture has legal-person status. Organisations enter into an equity joint venture often plan to establish a long-term business in China.

2.2 Cooperative venture

Cooperative venture is sometimes called contractual joint venture in which each party enters into a contract but acts as a separate legal entity and bears its own liabilities. Such joint venture may take any co-operation form agreed between the two partners, with each party's rights and obligations specified in the contract. Usually the Chinese partner would provide contributions as part of its stake in the kind of land, natural resources, equipment, labor force and public utilities, etc. The foreign partner usually provides capital, advanced technology, key equipment, materials, management skills, etc. The cooperative joint venture is usually in a more flexible form of investment bound by fewer statutory provisions. Cooperative joint venture usually is project based. This kind of enterprise can be developed quickly to take advantage of short-term business opportunities and dissolved when they complete their projects.

2.3 Development of sino-foreign construction joint ventures in China

Almost all the foreign firms in China entered into the Chinese construction market through forming sino-foreign joint ventures. There are very few wholly foreign owned enterprises as they will have to go through many procedures for approval, which will take a long period of time. Because of the cultural and language barriers, few overseas companies will like to go through these procedures by themselves. The government has been encouraging foreign firms to set up joint ventures with local firms. As it is in line with the government's interest, a joint venture will find much easier to pass through approval procedures. Furthermore, wholly foreign owned firms are strictly limited to work with certain projects. China is cautiously opening its construction market to overseas. Even joint ventures are still only allowed to participate certain projects such as foreign invested projects, the World Bank projects, and the projects concerning with advanced technology [6].

The rapid development of applying competitive tendering approach has provided opportunities to overseas firms. In Shanghai, for example, there was no foreign contractor up to 1984 when the system of tendering was just introduced to the Chinese construction industry. But, by 1994, 72 foreign contractors and 3 1 designers had entered into Shanghai construction market through forming sine-foreign joint ventures [5]. Up to the middle of 1996, the Ministry of Construction of China and municipal governments had given licenses to 118 large foreign firms who, in collaboration with local firms, have implemented more than 140 large construction projects. And significant number of medium projects is obtained by joint ventures [2]. Joint ventures in the Chinese construction are becoming a major party in the Chinese construction.

3 Risks to the sino-foreign joint ventures in the Chinese construction

Whilst construction industry is usually said to involve more risks and uncertainties, it appears that a sino-foreign joint venture in the Chinese construction is subject to much more uncertainties because of the special characteristics of the Chinese construction market. Several special risk areas are presented as follows:

3.1 Risk of finding partner

As there are many different overseas and domestic construction companies with different level of quality and capability, both two parties in a joint venture will face the risk of having an 'uneasy' partner to work with. Usually, overseas companies like to find their partners from those large state-owned companies. However, these companies often have a complicated and bureaucratic system, and their top managers are usually appointed by government. It happens that the top management staffs are changed suddenly. Furthermore, there is a risk that large companies have huge registered capital and assets but little real cash flow. The improper arrangement of partner can lead serious disputes, consequently, substantial losses can occur. In a commercial building project developed by a sino-foreign joint venture in Shanhai, the foreign partner suggested to select the main contractor through selective tendering, but the local partner insisted to employ its own construction team as the main contractor for the project. Due to the application of inappropriate technology and building methods by that main contractor, settlement occurred to the adjacent factory and its production line was damaged during the basement excavation of the project. The factory owner sued the joint venture and requested for damages. The main contractor denied the liability and refused to attend any meeting for negotiation and settlement. Finally, the case was settled through mediation and the joint venture had to reimburse the factory owner for the damages. During the construction, it was also very difficult to control the main contractor on time and cost aspects such as the negotiation on rates of new items as the main contractor was the local partner's own subsidiary firm.

3.2 Legal and policy risk

The market economy system is still being established in China, and governmental policies are subject to various changes. There are many provisional policies and legal regulations issued by both the central government and local governments, which will be revised or updated as the reform progresses. The variations of governmental policies and legal regulations can have significant impact on the financial picture of a joint venture project. This can be demonstrated by a particular case. A joint venture project is located in an old city in Guangdong province, and over 1600 families used to live in the project site. The local government planned to redevelop the site into a high class residential area. One of the critical issues in the contract arrangement was about the resettlement for those who used to live in the area. According to then governmental resettlement regulations, those residents affected by the construction of financial, commercial and high-class residential buildings should be permanently resettled to the area outside of their original living location. The resettlement work started accordingly. However, after less than half of the families having been resettled, the local government issued the new resettlement policy. By new policy, if the demolition of the old building is caused by the construction of residential buildings, those residents affected should be resettled back to their original living district upon the completion of the redevelopment. The new policy is in effect and applicable to all projects irrespective of the date of signing contract. Due to the sudden change of the resettlement policy, the saleable floor area from the development has been dramatically reduced. As a result, the profit of this joint venture project is expected to drop by over 50%.

On the other hand, as local governments issue various “additional”, or most often “temporary” policies, there is a risk that some of these local policies may not be recognized by the central government. The implementation of joint venture projects according to local policies may not satisfy the central governmental policy, consequently, the investor may suffer from such policy variation.

3.3 Technical risk

The operation of a joint venture is also subject to commonly defined technical risks, such as mistake in design; improper technology; shortage of materials, plant and labour; damage to built works; injures and accidents to working staff; damages and accidents to third party; natural disaster, etc. However, one major technical risk involved in a sino-foreign joint venture project is due to the different building practice applied in China and overseas. In a commercial building project developed by a joint venture in Beijing, risk happened due to the difference of technical building practice. The incident was about the co-ordination for laying E&M conduits, which was undertaken by a nominated E&M subcontractor.

Under the main contract, the main contractor would be responsible for attending to the works of the nominated subcontractors, which is a usual arrangement in international practices. However, during the normal inspection of the construction works, the joint venture’s work supervisor received the complaint from the E&M contractor, that the masonry workers hired by the main contractor were damaging the vertical conduits laid earlier by the E&M contractor. The supervisor went to the spot to check and found that all the vertical conduits were bent outwards from the structural brick walls instead of having concealed in the walls as required by the drawings and specification. When questioned, the local workers setting the brick walls revealed that the common practice of finishing the works in China was in the pattern of one trade following another. In this case, the sequence should be to erect the structural brick walls, to make the chases for the conduits, to lay the conduits by the E&M contractor, and to apply finishing to conceal the conduits. When the masonry workers started their work, they found that vertical conduits were installed and obstructed their operation. They therefore bent the conduits (some conduits were even pulled out and set aside) in order to make way for setting their brick wall. When the supervisor discussed the case with the main contractor, the main contractor blamed E&M contractor and asked for compensation for abortive works. As the different practice has not been speculated in the contract, the joint venture developer has to compensate the main contractor.

3.4 Risk in bidding

The competitive tendering approach has not yet been fully established in the Chinese construction industry. As many small or medium sized state-owned construction companies have no competition strength, the government departments have to protect them by assigning them certain projects for them to survive. Thus the current procurement practice in China is in fact a partial competition system which includes both competitive tendering and administrative assignment. It appears that only World Bank and Asian Bank Projects and some other large projects are procured through open tendering approach. The local protectionism affects to a large extent the adoption of the open tendering method. Provincial localities normally issue various regulations limiting the participation of external construction firms to tender for local projects. The sino-foreign joint ventures are restricted to certain kinds of projects [1],[5]. The partial competition practice brings the poor transparency in the tendering process, in which a joint venture can easily loss.

4 Risk management strategies for the sino-foreign construction joint ventures

Risk management is usually defined as a system including risk identification, risk analysis and risk response. Previous studies have provided a wide range of risk management strategies for the businesses in the construction industry. Typical strategies are suggested as contractual risk transfer or allocation, risk reduction by adopting alternatives, risk control or taking by applying risk premium, etc. [7]. Whilst all these methods are applicable to managing risks involved in a sino-foreign joint venture in the Chinese construction, the following studies will investigate several typical risk management approaches applied in China.

4.1 Good relation with local government

To operate a sino-foreign joint venture in the Chinese construction, it is extremely important to maintain good relationships with local government. A Hong Kong developer formed a cooperative joint venture with a local state-owned company for developing a multi-function building in Shanghai. Upon the completion of two-third of the project, the government proposed to extend a ramp for an existing bridge that is adjacent to the project. This proposal would result in the blocking of the shop-front of the building facing the ramp extension, and the red line of the site would have to move backward. However, as the joint venture has established very good relationship with the local government, the negotiation has led to the change of the direction of the ramp extension. Consequently, not only the shop-front of the building will not be blocked, but the value of the building has also been enhanced as the new ramp improves the traffic flow, thus enhances the location value of the building.

4.2 Contractual risk allocation in equity joint venture

An equity joint venture is to look for a long-term business, thus it is important to establish an organisation in which risks are properly allocated. Main concern must be given on who is more capable to control risk. In a practical case, the foreign partner successfully transferred all technical risks, and protected safely his interests through contractual arrangement. The local partner is responsible for the management of construction and operation of the project. The project is a power plant with the capacity of 2x150MW located in Southwest China. The total investment for the project is about US$290 million. The project is offered to an equity sino-foreign joint venture with 20 years of cooperation period. The local partner is a state-owned power company, and the foreign partner was selected through selective tendering among six international companies. The contract includes the following major terms:

Investment amount: 38% equity, 62% shareholder loan;
Equity IRR not less than 15%, interest rate for loan not less than 10%;
Preemptive amortization for the investment by foreign party;
10 years payback period,
Local partner being responsible for the extra costs due to the construction risks including delayed time, poor quality, etc.;
Local partner assuming all operation and maintenance risks to ensure that the operation hours of 5000per year.

Thee joint venture also buys insurance against the risk of breaching contract by either party.

4.3 Risk control in cooperative joint venture

Most of the sino-foreign cooperative joint ventures are project-based ventures. Project management procurement system is widely applied in controlling risks in such joint ventures. For a typical sino-foreign cooperative joint venture on commercial or residential building projects, the foreign party will assume the duty of overall project management. The main contract of construction work will be offered mainly through negotiation to a local construction company, suggested by the local partner of the joint venture. Upon foreign party's request, selective tendering method can be used for selecting the main contractor. Sub contracts will be normally offered through selective tendering process, in which both overseas and local firms can be affected. The professional consultant is usually recommended by foreign party, and building supervision team will be from the local party's advice. In fact, foreign party in such arrangement takes the role of project manager, and the local partner assumes the role of construction manager who is responsible for all technical risks. Such arrangement has been found very effective in controlling joint venture risks.

4.4 Share of legal risk with relevant government department

As many government departments have their own subsidiary construction companies, it is an effective way to appoint such companies to undertake works in joint venture projects. For example, in the previous case discussed in the section of legal risk, the joint venture has appointed a subsidiary company of the Construction Commission of the local Government to undertake the resettlement work. Through this arrangement, most of the risks related to the resettlement work have been passed over to this subsidiary company. The joint venture believes that the governmental department will re-adjust the relevant policies in finding a way out because of the pressure from its own subsidiary company. Hence, even though that issue has not yet been resolved, a moderate solution can be expected.

5 Conclusion

This study demonstrates that the huge construction market in China has attracted many foreign firms since the beginning of 1980s. Majority of them works in China by forming joint ventures with local partners. The participation of foreign firms has contributed significantly to the development of the competitive construction procurement practice in China. There are a number of risk areas affecting the operation of construction joint ventures in China. This paper has identified the major risks affecting the sino-foreign joint ventures, such as legal and policy risk, technical risk, partnering risk, etc. It is important for a joint venture to have a clear picture of the future risk profile involved in their businesses in order to take proper risk management strategies.

Reference:

1. Shen L Y, et al (1996) 'The application of BOT System for Infrastructure Projects in China' *Journal of Construction Engineering & Management, ASCE,* Vol. 122, No.4, pp3 19-325.
2. Daud A & Zong Y (1996) 'Overview of the Building Industry in China' *Proceedings, CIB International Conference 'Construction Modernization and Education'* Oct. 21-24, Beijing.
3. CSB (1996) *China Statistics Yearbook* (199.5' China Statistics Publications, Beijing.
4. Zhou G Z (1996) 'China in its reform and opening-up and Chinese construction industry on its way to prosperity' *Proceeding of 1996 CIB International Conference 'Construction Modernization and Education'* Oct. 2 l-24, 1996, Beijing.
5. Shen L Y & Fan X J (1994) Construction Market for Overseas Contractors in China (Shanghai)' *Proceeding of the 21st annual meetings of CIB working commission W-55 Building Economics* Sept. 6-9, 1994, The Hong Kong Polytechnic University, pp119-134.
6. Yao B (1997) 'Prospects of China's Construction Industry', *Proceedings of The 3rd ASIACONSTR UCT Conference – Opportunities for Intra-Asian Cooperation, 26-27* Nov. 1997, The Hong Kong Polytechnic University, Hong Kong.
7. Flanagan, R. & Norman, *G.* (1993) *Risk Management and Construction* Blackwell Scientific Publications.

Procurement Sustainable Building Practice

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Abstract
Two aspects will be stressed in the frame of this topic:
The Procurement Aspects and the Aspects of Conflict and Dispute Resolution.
The Right for Environment - to introduce the following aspects - is not only the consequence of care-taking for Nature as an admirable phenomenon, but also as a source of nearly all what is needed for humankind of today and tomorrow. The legal practises - of course - have not only to fulfil1 the current valid laws and guidelines, but they have to be based on an ethic and even altruistic behaviour.
Against the background of so many shrinking resources, we have to look for sustainable and renewable sources and have to choose for those building practises which clearly contribute towards sustainability. The important procurement problems can be handled in research as well as practise by the applications of the Material and Energy Choice and Selection Method, which is summarised in a Matrix. This Matrix - as a rule of thumb - can help to choose consciously concerning the bigger or lesser effects and side effects which sooner or later will go hand in hand with the choosen practises and technologies.
Since building is teamwork, always - except an hermit alone builds for himself - Conflict and Dispute Resolution is most important. The Method Holistic Participation - MHP - serves this purpose excellently and can be applied for problem solving of nearly each complex task, in which different, even opposing parties will participate. Based on very old experiences, firstly applied by Konrad Wachsmann and Walter Gropius in Building Technology in the fourties and further developed by the author, it is possible to use this method effectively in order to reach common solutions mainly by consultation and in consensus.
Beside the importance of Legal and Procurement Practices and the Right for Environment it will at least be necessary to consider Management as a key to get the' things done. The Indoor Climate as the reason wherefore we build and Materials and Technologies, which are strongly related to procurement problems, which are 'responsible' for the materialisation and realisation as well - have to be taken in consideration.
Together with a responsible view on those fields, it will be a 'conditio sine qua non', to handle the absolute principle of care-taking in legal and procurement practises, considering the whole of humankind in the radically smaller getting world.

Keywords: Method holistic participation and care-taking

Procurement Sustainable Building Practice

Two aspects will be stressed in the frame of this topic:

The Procurement Aspects and the Aspects of Conflict and Dispute Resolution.
The Right for Environment - to introduce the concerned aspects - is not only the consequence of care-taking for Nature as an admirable phenomenon, but also as a source of nearly all what is needed for humankind of today and tomorrow. The legal practises - of course - have not only to fulfil1 the current valid laws and guidelines, but they have to be based on an ethic and even altruistic behaviour.

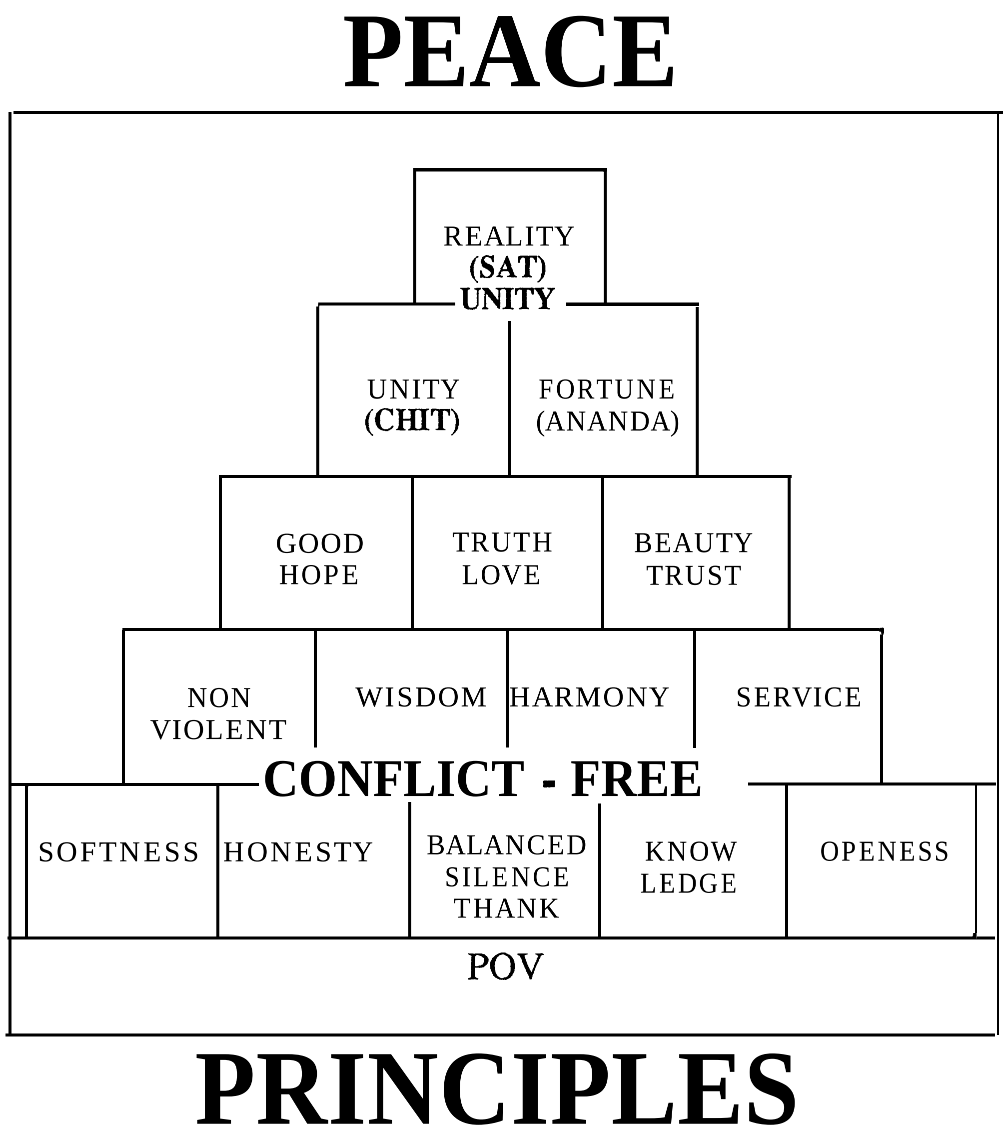

Figure 1
The Pyramid of Virtues shows the behaviour qualities which have to be respected in order to give to Science and Technology a direction towards responsible processes and results.

Against the background of so many shrinking resources, we have to look for sustainable and renewable sources and have to choose for those building practises which clearly contribute towards sustainability. The important procurement problems can be handled in research as well as practise by the applications of the Material and Energy Choice and Selection Method, which is summarised in a Matrix. This Matrix - as a rule of thumb - can help to choose consciously concerning the bigger or lesser effects and side effects which sooner or later will go hand in hand with the choosen practises and technologies.

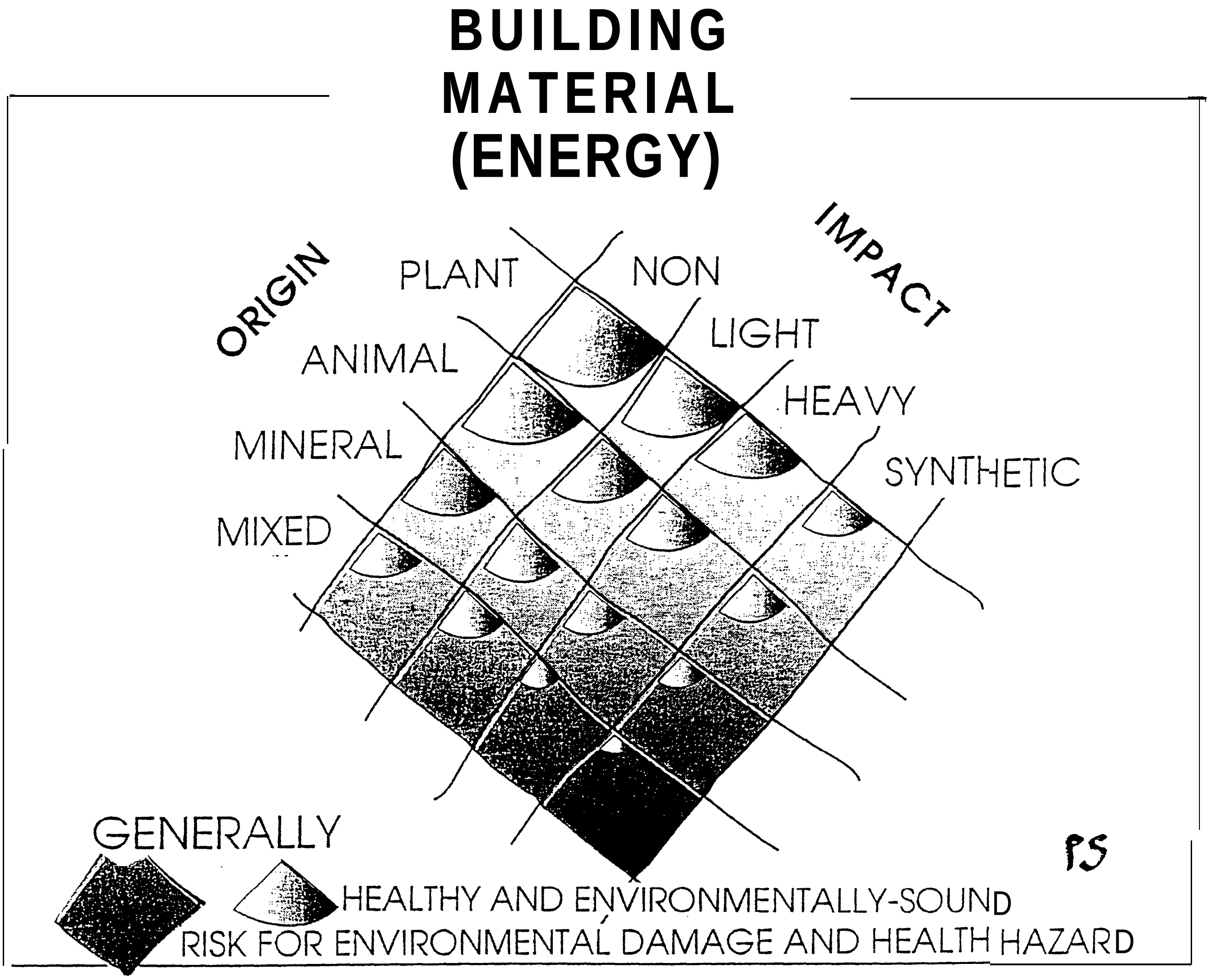

Figure 2
The evaluation of the impact of the use of materials (and energies) on health and environment is already roughly possible by the means of the Material and Energy Choice Material.

Since building is teamwork, always - except an hermit alone builds for himself - Conflict and Dispute Resolution is most important. The Method Holistic Participation - MHP - serves this purpose excellently and can be applied for problem solving of nearly each complex task, in which different, even opposing parties will participate. Based on very old experiences in pre-industrial societies, firstly again applied by Konrad Wachsmann and Walter Gropius in Building Technology in the fourties and further developed by the author, it is possible to use this method effectively in order to reach common solutions mainly by consultation and in consensus.

Figure 3
The Logo of the Method Holistic Participation symbolizing the rol play's of co-operating (expert) persons or teams, who in a weaving rotation - even starting with opposing opinions - can come to consensus.

Beside the importance of Legal and Procurement Practices and the Right for Environment it will at least be necessary to consider Management as a key to get the things done. The Indoor Climate as the reason wherefore we build and Materials and Technologies, which are strongly related to procurement problems, which are 'responsible' for the materialisation and realisation as well - have to be taken in consideration.

Together with a responsible view on those fields, it will be a 'conditio sine qua non', to handle the absolute principle of care-taking in legal and procurement practises, considering the whole of humankind in the radically smaller getting world.

Figure 4
Example(s) of Sustainable Building for various purposes illustrate the practical possibilities.

References

- Schmid, P. (1982), *Climate Habitat Culture,* International Seminar CHC at the Eindhoven University of Technology.
- Schmid, P. (1986) *Bio-Logische Baukonstruktion, Wege zu einer integralen Bau- und Ausbautechnik,* Mensch- und Umweltorientierte Hochbaukunde, Atlas einer human-okologischen Baukonstruktionslehre, Verlagsges. R. Müller, Köln.
- Schmid, P. *(1986) The Instrument of an Integral bio-logical Architecture, designaids for housing and built environment,* 1 lth World Congress of Sociology, New Delhi.
- Schmid, P. (1986) *Holistic and Bio-Logical Light Weight Structures for Healthy and Individual Housing* 1 st international conference on lightweight structures in architecture, Sidney.
- Schmid, P. *(1986) New Building Concepts on Totality-Proces-Detail - Ecological Architecture* (SHE), Congres of the Society for Human Ecology 'Human Ecology: Research and Applications', Bar Harbor, Maine, U.S.A.
- Schmid, P. (1987) *Integral Bio-logical Architecture,* 13. Kongress der Internationalen Gesellschaft zur Erforschung von Zivilisationskrankheiten und Umwelt (SIRMCE), Lausanne.
- Schmid, P. (1987) *The Gaia Building System,* International Conference on the Design and Construction of Non-Conventional Structures '87, London.
- Schmid, P. (1988) *Architecture-Ecology-Health,* 3rd International Conference of the Society for Human Ecology - SHE - San Francisco, U.S.A.
- Schmid, P. (1989) *Building on Peace,* Key-note paper, International Prague Assembly of architects, planners and designers for professional actions against ecological disaster, homelessness and armament race, Palace of Culture Prague, CSFR.
- TUE, IFAM (1990) *Minimalisering van de Milieubelasting in de Woningbouw* , onderzoekrapport, i.o.v. Stichting Milieubewustzijn, Hilversum, Amsterdam - Eindhoven.
- Schmid, P., Haas, M. (1990) *Bio-logisch bouwen en wonen, gezond voor mens en milieu,* A&h-Hermes, Deventer.
- Schmid, P. (1991) *House of Another Future,* 9th International Svedala Symposium on Ecological Design, Svedala, Sweden.
- Schmid, P. *(1992) Integrated Development (Gaia Building Systems), European Cities: Growth and Decline,* International Conference in The Netherlands, Den Haag.
- Schmid, P. (1994) *Sustainability and Building,* CIB Conference, U.S.A.
- Schmid, P. (1995) *The World a Green School for Everybody,* Environmental education for the whole society, A contribution towards sustainable environment,' International Conference Environmental Issues Education and Training, University of Mateja Bela, Banska Bystrica, Slovak Republic.
- Schmid, P. (1995) *Sustainable Architecture,* International Symposium 'A Vision of architecture of the 2000's: Green and glocal architecture' on behalf of the 50th anniversary of the AIK-Architectural Institute of Korea, Seoul, Korea.
- Schmid, P. *(1996) The Different Houses of the Nations on one World, The common Sustainable Habitat reflected in the Joint,* XXIVth IAHS World Housing Congress, Ankara, Turkey.
- Schmid, P. (1997) *Architecture for Sustainable Peace,* International Conference Environment and Society: Education and Public Awareness for Sustainability, organized by UNESCO and Greece, Thessaloniki, Greece
- Schmid, P. *(1997) Sustainable Architecture, based on and related to environment-ethics-peace,* International Academic Conference, Environmental Justice: Global Ethics, The University of Melbourne, Australia
- Schmid, P., P'al, G., Liddell, H., Halliday, S. (1997) *Green Arrows from Gaia International,* Sustainable Architecture in Auckland and Wellington, New-Zealand.
- Schmid, P., Liddell, H. (in preparation) *An Introduction to Ecological Design.*

Planning techniques and environmental issues in procurement

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Abstract
The paper aims to explain how procurement methods for Public Works in Italy based upon severe networking planning techniques could improve quality, safety and environmental management,
Furthermore, environmental issues are related to refurbishment works, that are more and more increasing in the Western Countries.
Finally, effective procurement methods (construction management based) minimise environmental degradation especially when an integrated project plan is required by clients and owners.
Keywords: environmental management; project management; health and safety planning.

1. Resource planning and environmental management

Resource management is becoming the key issue in our research concerning project planning techniques for environmental and safety management in tendering and contracting into the construction industry.
Furthermore, refurbishment works, that are very often made in the inner cities and towns, the inhabitants living within buildings to be refurbished, are the most sensitive.
Our studies were, firstly, focusing on links and relationships amongst activities (already constrained by various parameters), because of the usefulness of lags and floats in ascertaining and diminishing environmental and safety risk factors and levels.
For instance, the need to reduce overlaps is well known, even if, for example, in refurbishment and rehabilitation works uncertainties are overwhelming the planned approach.
Nevertheless, the critical agents seem to be non financial resources (labour, plant, equipment, materials) rather than activities, the former being more timing and scheduling driving: in any case activities are carried out by resources.
For this reason, we are purporting that is advisable to plan the extremely large number of resources involved on even the smallest rehabilitation site in a deeper detail for the task of grouping.
For planners it could be a mistake to group all the resources into a single resource or, at the very worst, considering only the key one.
In other words, we have begun to establish resource-based models instead of the traditional activity-based ones, because of the accuracy more and more required in the advanced project planning practice.
Planners are continously trying to allocate only few, main resources (usually, no more than three) to each activity to monitor effectively cost and cash flows, but, from an environmental and safety risk management oriented viewpoint, critical resources could not be of necessity the most expensive ones or the scantiest ones.
Or, finally, the resources which are assigned to activities laying on the critical path could not be interesting to control closely.
Till now resource profiles and levels have been used chiefly for determining activity durations and resource-driving costs (excluding environmental and safety costs derived from a bad allocation of the available resources): above all, resource demand has been envisaged when levelling and smoothing was needed.
In so doing, planners are neglecting dangerous interfaces between resources and inhabitants or sites.
It is important therefore that due care is taken in selecting and assigning resources, knowing their productivity but also environmental and safety riskiness.
Human resources on sites (engineers, planners, quantity surveyors, quality managers, safety officers, skilled craftsmen, labourers, bricklayers, plasterers, and so on) have to be trained about environmental management.
Human resources, which are handling materials and driving plants and equipments can, indeed, interact each other causing safety problems.
Furthermore, same gangs could interact with the inhabitants (on refurbishment sites) and the environment causing environmental problems.
Meanwhile, we have performed an examination considering real, abstract and space resources, particularly on new factory building sites.
Lack of space, for instance, is often a dangerous restriction during the execution of an activity.
On construction projects, space, as a primary factor for storage, is limiting quasi-inconsistent operations which take place together.
Planners are going to define exactly space resources and spatial constraints for activities, operations, real resources.

Likewise, abstract resource management is needed to avoiding that two or more incompatible or dangerous activities (from the environmental and safety perspective) do not happen at the same time.
On the other hand, clients wishing to increase environmental and safety management must acknowledge proportionately, on the bid and award phases of the tendering, accrued costs carried out by contractors in reducing overlaps and interactions.
Planners find often difficult to develop a plan of works which consider every resource independently for various purposes: so, it is better to identify the environmental and safety most sensitive resources.
Moreover, key resources have to be analysed with regard to the assigned activities: to prevent likely risks we have to foresee the pattern of resources (single or multiple type) required by activities over its durations.
The variation of the resource level demanded by an activity is the main topic we have examined, together with the moving of the resources visiting different activities on the same place on the same day or week.
It is necessary, on sites, to plan and control a host of multiple variable resource demand activities to reduce risk levels.
We are recognizing, by measures kept on the field, that quantities of resource allocated to an activity is often far from to be constant: quite for the same type of work included in the activity considered, keeping into account uncertainty built in a project, when the activity duration is also variable.
Of course, managers and planners usually think that it is an unuseful waste to spend time and money in producing a more realistic and accurate resource demand model for the cost control purposes.
As a matter of fact, if a deal of activities in a plan of the works is encompassed, it is advisable to accept the constant resource demand from a statistical viewpoint, but concurrent environmental and safety key activities should not be managed ignoring variable trends.
When such a condition occurs, planners find convenient to split the large variable resource demand activity into a number of smallest constant or less variable demand sub-activities containing as less key resources as possible: to do it, they have to detail, or even change, method statements.
Consequently, resource-duration relationship seems to be very difficult to forecast and plan: for instance, changes in the size of gangs is frequently happening.
It must be remembered that firms involved in refurbishment projects are seldom large: unplanned stops of occuring activities push top managers to assign their involved key resource (the non storable ones, over all) to other activities, lessening the realism and the reliability of the plan.
The aim of reducing risk levels for environmental and safety aspects planning requires more adequately resource demand profiles on a project, but it is further endangered by the behaviour of subcontractors, which tend to plan their own work independently, ignoring the master resource plan and neglecting working rates of the other firms and gangs together with interact and overlap on the same place.

2. Environmental issues in the tendering and awarding methods

The client organisation plays a key role in environmental and safety management over the tendering and awarding stage, because it is able and, above all, must force bidders, tenderers (and, later, contractors) to plan effectively the works to be done, without exceeding all bounds to reduce project duration by means of the crashing technique.
Client organisation should select, at the pre-qualification stage, only building contractors complying with (or certified against) the widespread Standards IS0 9000 and 14000: bui it is not enough.

However we are testing some methods to evaluate and monitor - on the behalf of clients' representatives - resource plans provided by bidders at the tender stage.

Such methods could allow clients to award tenders to the higher environmental and safety oriented bid rather than to the lower cost effective one.

We are trying to establish a procedure to force bidders, on a contractual basis, to show links, relationships, lags, among purchasing, storing, handling and constructing activities: latest start and finish times of the activities are not adequate, in our opinion, to ensure environmental and safety risk reduction.

Bar and network charts have been organized in a different manner, easier understandable: it seems better to filter activities laying on charts by risk items, to group fragments of network according to different environmental and safety risk levels.

Furthermore, we aim to define site-related time-space charts (similar to time-chainage charts used on road works) to visualize activities carried out in the long run: from a spatial perspective.

Clients could support, through settling criteria of interim and final payment accounts, those contractors that are wishing to foresee in detail, before signing, resource consumption curves (linear and non-linear distributions), from a qualitative point of view, at least, together with all the splitting, stretching and crunching attempts made when planning.

Contractors (clerk of works) should be acquainted with non-linear and variable resource demand curves concerning activities laid on the network

Moreover, the client organisation, after signing the contract, should timely require the contractor to provide not only the site lay-out and the master plan of works, but also detailed fragnets (planned by specialist firms) and a resource bar chart encompassing the main real resources to be assigned to activities and place on site.

Finally, such a mandatory document as the health and safety plan (in the EC countries) could be enlarged to include the environmental issues.

Undoubtfully, construction management based procurement methods allow a closer project information exchange between clients and contractors about resource management.

Otherwise, the adverse relationship between counterparts built in traditional procurement paths, which are not at all waning in popularity, could lead to litigations about damages and casualties.

As resource management shows, a cooperative and consistent effort is absolutely needed to prevent such events.

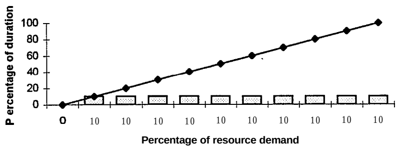
3. References

1. Ciribini, A., Rigamonti, G. (1997) Computer Network-based Models and Construction Management A Critical Analysis in the Italian Construction Industry, ***Computers in the Practice of Building and Civil Engineering*** Worldwide ECCE Symposium Report, RIL, Helsinki.

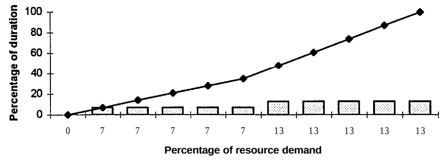
Activity ID	Description	Original Duration	Early Start	Early Finish	Budgeted cost	WBS Code	Activity Risk
A1 - NUOVO INSEDIAMENTO INDUSTRIALE							
		196	12SEP97	24JUN98	5 231 140		
AI.01 - TERRENO							
		0	17NOV97	17NOV97	1 540 000	AI.01	
10	Acquisto terreno	0	17NOV97		1 540 000	AI.01	
AI.02 - PROGETTAZIONE, D.L. e COORDINATOR1							
		196	12SEP97	24JUN98	225 000	AI.02	
20	Progettazione arch per ritiro concessione	15	12SEP97	02OCT97	30 000	AI.02	
30	Progettazione strutturale	10	17NOV97	28NOV97	10 000	AI.02	
40	Progettazione esecutiva edifici/impianti	0	01 DEC97	28NOV97	50 000	A1.02	
50	Presentazione pratica edilizia	0	03OCT97		0	AI.02	
60	Ritiro concessione edilizia	0		28NOV97	0	AI.02	
65	INIZIO LAVORI	0	01DEC97		0	AI.02	
70	Direzione dei lavori	140 *	01 DEC97	24JUN98	100 000	AI .02	
80	Direzione lavori opere c.a.	75 *	01 DEC97	25MAR98	10 000	AI .02	
85	Coordinatori per la sicurezza	140 *	01 DEC97	24JUN98	25 000	AI.02	
AI.03 - ONERI E OPERE DI URBANIZZAZIONE							
		135	28NOV97	17JUN98	171 840	AI .03	
90	Oneri primari	0		28NOV97	31 360	AI.03	
100	Oneri secondari	0		28NOV97	17 640	AI .03	
110	Smaltimento rifiuti	0		28NOV97	7840	AI.03	
120	Opere di urbanizzazione esterna	20	21MAY98	17JUN98	115 000	AI.03	2
AI.04 - COSTRUZIONE							
		140	01 DEC97	24JUN98	3 020 300		
A1.04.A - Opere preliminari al montaggio del prefabbricato							
130	Demolizioni	5	OIDEC97	05DEC97	22 000	A1.04.A	8
140	Scavi e reinterri	7	08DEC97	16DEC97	42 000	AI .04.A	4
150	Opere in cement0 armato gettate in opera	20	17DEC97	23JAN98	158 000	AI .04.A	4
160	Sottofondi in ghiaia grossa	10	19JAN98	30JAN98	150 000	AI .04.A	3
A1.04.B - Montaggio prefabbricato e opere complementari							
165	Montaggio struttura	8	02FEB98	11FEB98	916 000	A1.04.B	12
170	Completamento copertura	20	26FEB98	25MAR98	229 000	AI .04.B	12
180	khiusure verticali opache	10	12FEB98	25FEB98	540 000	A1.04.B	12
190	Serramentistica	15	26FEB98	18MAR98	68 300	A1.04.B	9
200	Pot-ton i d'accesso	10	26FEB98	11MAR98	22 000	A1.04.B	4
A1.04.C - Opere completamento							
210	Smaltimento acque bianche e nere	35	12FEB98	01 APR98	92 000	AI .04.C	2
220	Sottofondo ghiaia fine e pavimenti	20	19MAR98	15APR98	190 000	A1.04.C	2
230	Blocco servizi - spogliatoi - uffici	30	02APR98	13MAY98	61 000	A1.04.C	2
240	Rete esterna servizi	35	02APR98	20MAY98	165 000	A1.04.C	2
245	**CONSEGNA** EDIFICIO	0		28MAY98	0	A1.04.C	
A1.04.D - Opere esterne							
250	Recinzioni e cancelli	20	21MAY98	17JUN98	94 000	A1.04.D	1
260	Finitura piazzali e strade	25	21MAY98	24JUN98	175 000	A1.04.D	1
270	Opere murarie per corpo in aggetto zona ribalte	10	12FEB98	25FEB98	96 000	AI .04.D	8
271	**FINE LAVORI**	0		24JUN98	0	A1.04.D	
AI.05 - IMPIANTI							
		65	26FEB98	27MAY98	274 000	AI .05	
280	Impianto riscaldamento	35	09APR98	27MAY98	50 000	AI.05	3
285	Impianto elettrico	1	16APR98	16APR98	134 000	AI.05	4
290	Rampe elettroidrauliche e pot-toni sezionali	5	26FEB98	04MAR98	90 000	AI .05	2

RESOURCE / DURATION CURVES

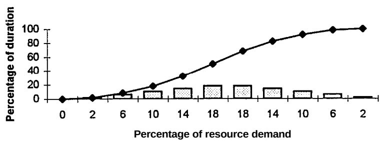
Designator 0 - LINEAR



Designator 4 - BACK LOADED



Designator 1 -TRIANGULAR



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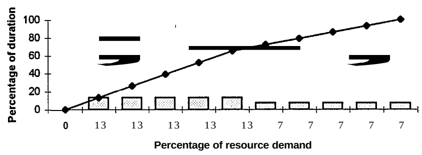

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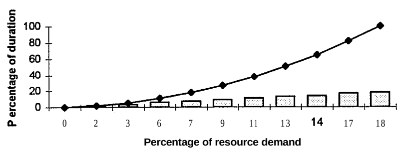

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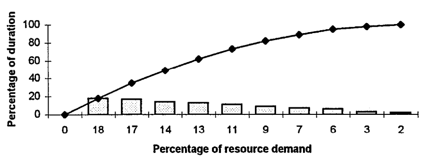
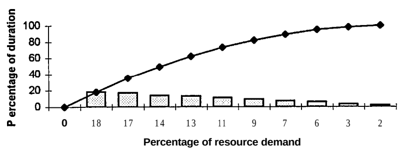
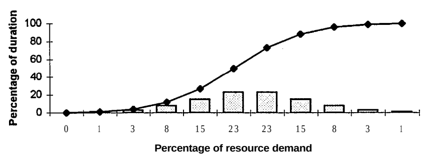


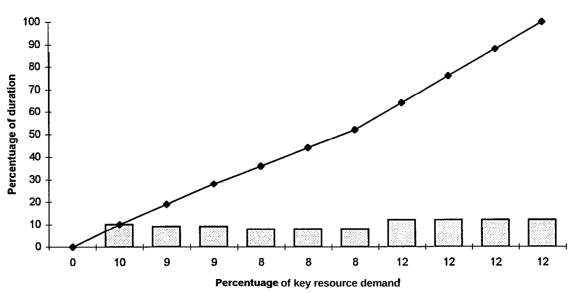
Designator 3 - TRIANGULAR DECREASE



Designator 7 - BELL SHAPE



MULTIPLE RESOURCE DEMAND TEST ACTIVITY



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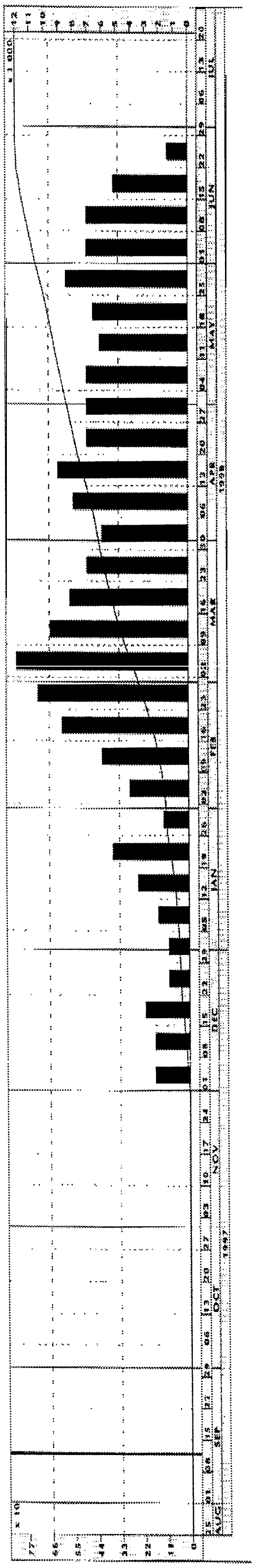
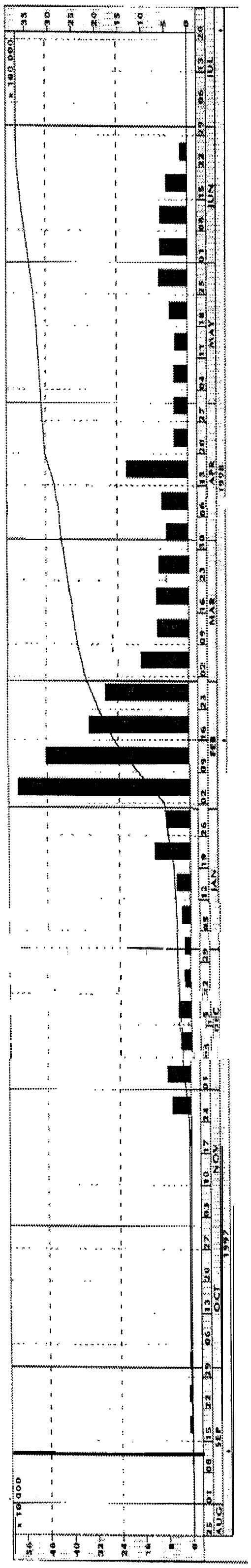
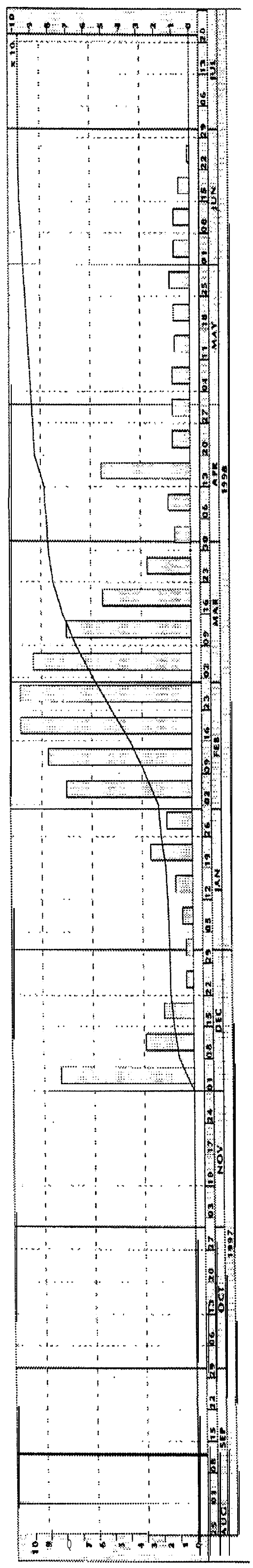
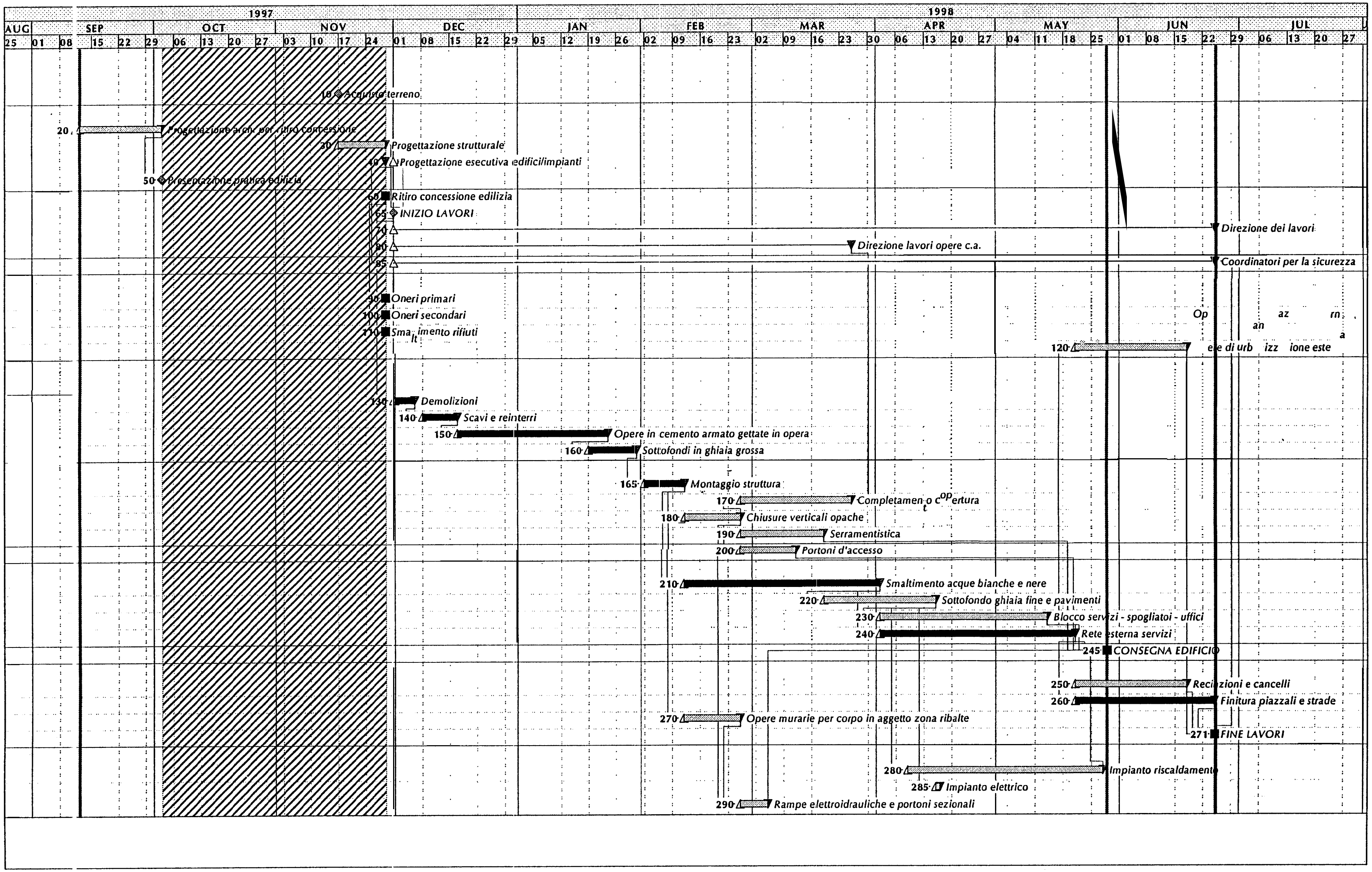
		
Resource Demand Profile 1	**Resource Cost Profile** 2	**E&S Risk Levels** 3


1997
1998
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL
10 Acquisto terreno
20 Progettazione arch. per ritiro concessione
30 Progettazione strutturale
40 Progettazione esecutiva edifici/impianti
50 Presentazione pratica edilizia
60 Ritiro concessione edilizia
65 INIZIO LAVORI
70 Direzione dei lavori
80 Direzione lavori opere c.a.
85 Coordinatori per la sicurezza
90 Oneri primari
100 Oneri secondari
110 Smaltimento rifiuti
120
130 Demolizioni
140 Scavi e reinterri
150 Opere in cemento armato gettate in opera
160 Sottofondi in ghiaia grossa
165 Montaggio struttura
170 Completamento copertura
180 Chiusure verticali opache
190 Serramentistica
200 Portoni d'accesso
210 Smaltimento acque bianche e nere
220 Sottofondo ghiaia fine e pavimenti
230 Blocco servizi - spogliatoi - uffici
240 Rete esterna servizi
245 CONSEGNA EDIFICIO
250 Recinzioni e cancelli
260 Finitura piazzali e strade
270 Opere murarie per corpo in aggetto zona ribalte
271 FINE LAVORI
280 Impianto riscaldamento
285 Impianto elettrico
290 Rampe elettroidrauliche e portoni sezionali

The Direction of Policies and Systems for the Development of Sustainable Human Settlements in Korea

- Focussed on Multi-Family Housing Estates -

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The Centre for Sustainable Construction, Building Research Establishment, Watford, UK

Abstract

As the Habitat Agenda was established at the Habitat II conference in 1996, the Korean goverment is planning to establish the Korean Habitat Agenda including policies and institutional systems which deliver development objectives that are compatable with the aims of sustainable development. Within this context, the aim of this paper is to establish the direction of policies and systems for the development of sustainable human settlements in Korea.

With this aim in purpose, this paper firstly extracts the indicators for sustainable human settlement from worldwide cases, and then surveys and assesses four representative housing estates in Korea with these. It then discusses the problems of achieving environmental sustainability in housing estates. Finally, this paper seeks to establish the developing direction of policies and systems for sustainable human settlements in Korea.The direction of policies and systems which are suggested are as follows.

To achieve sustainable land-use, a proper development density is proposed, while a conservation law for natural resources in residential development is also suggested. Secondly, for sustainable transportation, a development direction for an environmentally friendly transport system is advised to decrease both travelling distance and the need to use a private car, leading to a reduction in pollution.

Next, an energy saving layout control and a system using grey or rain water are promoted to save energy and water resources.

Finally, for the ecological environment, a legal instrument should be promoted to enable developers to introduce various kinds of biotops such as ponds, lakes, hills and so on. It could also provide for a green network as an ecological corridor within a housing estate and between housing estates and adjecent biotops. This has a very important role in both allowing animal movement and enhancing biodiversity in the development of sustainable human settlements.

Keywords: Sustainable human settlement, Habitat II, Indicator, Housing, Policy

1. Introduction

Nowadays, sustainable development has become a worldwide paradigm after the Bruntrant definition (World Commission on Environment and Development) : '... development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.[1] Also in residential development, sustainable human settlement is an important issue. The Habitat Agenda and the Istanbul Declaration came out of the Habitat II conference in 1996. The Korean goverment is proposing to establish the Korean Habitat Agenda including policies and institutional systems which deliver development objectives that are compatible with the aims of sustainable development.

The aim of this paper is to establish the direction of policies and systems for the development of sustainable human settlements in Korea. For this purpose, the paper does:

Firstly, understand the concept of sustainable human settlements through literature reviews, especially focused on the Habitat Agenda declared at Habitat II in 1996. And secondly, extract the indicators for sustainable human settlement from worldwide cases to assess the sustainability of the human settlements in Korea. After that, survey and assess the representative housing estates in Korea with proper indicators and then discuss the problems of the environmental sustainability of the housing estates and the direction of residential developments. Finally, this paper aims to establish the developing direction of policies and systems for sustainable human settlements in Korea.

2. The concept of sustainable human settlement

In Habitat II, sustainable human settlement development ensures economic development, employment opportunities and social progress, in harmony with the environment. It incorporates the principles of the precautionary approach, pollution prevention, respect for the carrying capacity of ecosystems, and preservation of opportunities for future generations.[2] Therefore sustainable human settlements can make a substantial contribution toward achieving sustainable development in all countries.

Written this agenda, there are several categories to develop sustainable human settlements. These are sustainable land use; social unity through overcoming poverties and creating jobs; sustainable environment; sustainable energy-use; sustainable transportation and communication systems; and finally conservation and restoration of historical, cultural, and natural heritages.

Among the categories of Habitat II, this paper focusses on the four physical categories which are sustainable land use, transport, energy use, and environmental quality including pollution and natural ecology.

3. Extraction of the indicators for the assessment of sustainability

This study reviewed various kinds of literatures regarding the indicators for developing sustainable cities and human settlements, especially focussing on casestuding in the U.K., Seattle, Delft, and British Columbia.3 Among the indicators which were extracted from the above casestudies indicators were selected which are more relevant and can be easily measured in the Korean situation. The selected indicators are as follows.

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1. World Commission on Environment and Development (1987), Our Common Future
2. United Nation Ceter for Human Settlement (1996), Habitat Agenda, Habitat II, Istanbul
3. Kyu In Lee Jae Joon Lee, Soo Ho Oh, Seon Young Jang (1997), Policies and Systems for the development of sustainablable human settlements, Korean Ministry of Construction and Transportation, pp. 1 O-25

Table 1. The indicators for assessment of the Korean housing estates

Classification	Issue	Indicator	Unit
Land use & Transport	Land use	*Household density *Conserved area	*units/ha *conserved area /total area
	Transport	*Commuting ratio on foot or by bicycle *Commuting ratio using public transport tools	• [illegible] •%
Environmental Quality	Air Quality	•the amount of SO_2 Emission *the amount of NO, Emission	• ppm/month • ppm/month
	Water Quality	• BOD *Distance from polluting origins (factory, cattle sheds, . ..)	• [illegible] • m
Energy	Energy Saving	*Ratio of south orientation of housing buildings	•%
	Renewable Energy	•Using ratio of solar energy	•%
	Water Economy	• Using ratio of greywater • Using ratio of rainfall	•% •%
Ecology	Water Friendly Space	*Distance from lakes, reserviors *Area of water friendly spaces	• m • m2/Person
	Greening , Spaces	*Area of green spaces *Distance from natural green spaces(forest, park, . . .)	• m2 • m
	Biotop	*Area of biotops *length of ecological corridor	• m2 • m
	Bio-diversity	• Bio-diversity of wild animal (birds, insects, fishes...) • Bio-diversity of plants	*species *species

4. **The survey results**

4.1 **Overview of the survey**

The aim of this survey was to assess the environmental situation and sustainability of Korean human settlements and draw out the problems. The scope of the survey covered the four categories, which are land use, transport, energy use, and natural resources as above. This survey focussed on 4 housing estates which are mainly multi-family housing estates in the new towns in Korea.

The examples were selected by residential density, the size of housing units, the building type(highrise or lowrise), the existence of a natural conservation area or not. They are representative of the types of multi-family housing estates in Korea.

Table 2. The overview of the sample housing estates

Case	Compl -etion	Size of land(m^2)	Number of units	unit/ha	Volume Ratio	Number of stories	Size of units(m^2)
Gwachon lowrise	1984	107,432	1,122	104.4	72.83	3-5	53-90
Bundang highrise	1991	122,588	1,781	145.2	227.0	5-28	66-23 1
Bundang lowrise	1995	17,205	240	139.4	158.3	4	66
Jungdong highrise	1993	36,926	1,008	272.9	228.0	14-25	57-105

4.2 The results of analysis

4.2.1 Land use

1. Residential density
In the above table, we can see the residential density is too high to achieve environmental quality compared to the exemplars in Australia(Table 7). In recent highrise residential developments, the volume ratios of most housing estates are over 200% while the household ratios are over 200units/ha. This results in overcrowded conditions and in lessening green spaces as well as introducing increased pollution and waste.

2. Conservation of natural resources
There is no strong legal or institutional system to prevent developers from destroying natural resources such as hills, forests, lakes, streams and so on. Therefore, it is very rare to conserve these in residential developments in Korea because the development density is too high. Moreover, in the development process, natural biotops such as, hills, forests, streams and so on, are almost always destroyed. The Gwachon newtown was a special case which preserved the natural resources because the Korean government had a special goal which was to develop it as a garden city while keeping the existing green spaces.

Table 3. Conservation ratio of natural resources

Case	Area of the conservation (m^2)	Conservation ratio(%)
Gwachon lowrise	15,610	14.53
Bundang highrise	0	0
Bundang lowrise	0	0
Jungdong highrise	0	0

4.2.2 Transportation

1. The commuting tools
Table4 shows that 54.6% of the residents use their car for commuting, while less than 10% of residents walk or use a bicycle. Among the four housing estates, the Gwachon shows the highest percentage use of public transport. This is because the residents in the Gwacheon newtown are situated close to use the subway. It is relatively small compared to the other estates, so most residents live near the subway.
The Bundang newtown also has a subway penetrating the newtown, but the size of the newtown makes access to the subway difficult for some residents. A higher percentage of people at the Bundang highrise use public transport as the subway is located relatively nearby, compared with the lowrise estate which is located at a greater distance from such resource.
Although the residents of Jungdong newtown are of relatively low income, they have the highest ratio of private car use because there is no subway available.

Table 4. The commuting tools (unit: %)

Case	walking/bicycling	public transport	private car
Gwachon lowrise	6	56	38
Bundang highrise	86 .	35.5	55.9
Bundang lowrise	8 8	30.8	60.4
Jungdong highrise	10 . 5	23.3	66.3
Total	8.4	37.0	54.6

4.2.3 Pollution

1. Air pollution
All the housing estates in our survey showed evidence of being over the environmental standard in SO_2, NO_2 especially during the winter season. Recently, there were several ozone warnings in residential areas of Seoul.

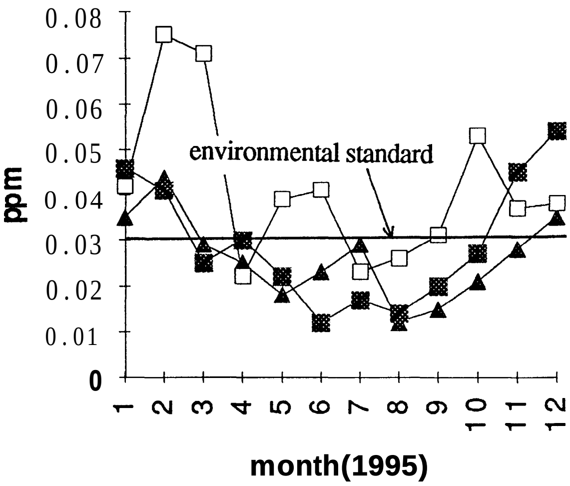

Fig 1. SO_2 emission

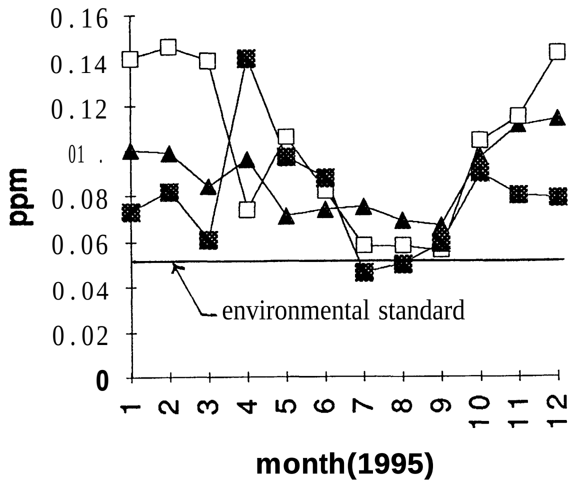

Fig 2. NO_2 emission

2. Water pollution
The BOD(Biochemical Oxygen Demand ;mg/l) in residential area are almost over 10, while the maximum is 35. This is a potentially harmful condition to aauatic animals and plants.

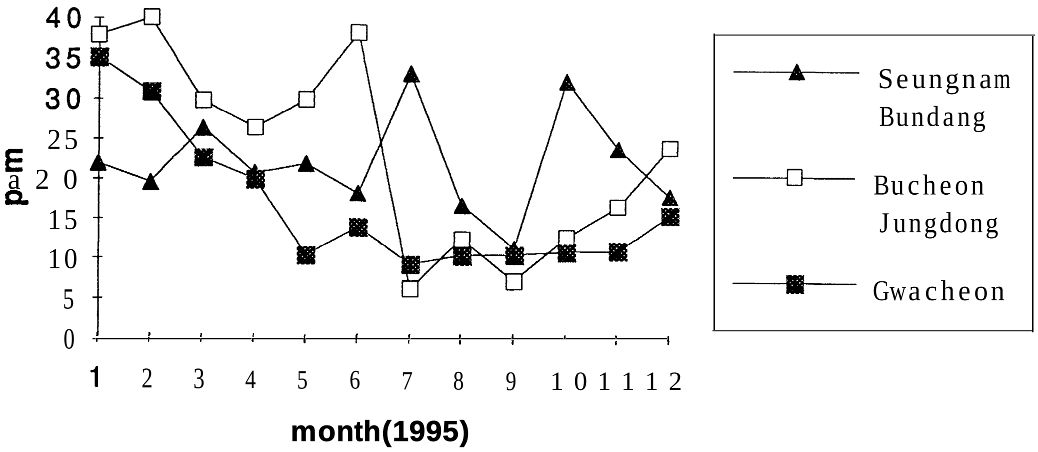

Fig 3. The BOD of the samples in the neighbouring river and stream

4.2.4 Energy saving
The orientation of housing is very important to residents because it is very cold during the winter season in Korea. But nowadays, due to higher development density the designer has to position buildings facing both east and west as well as south. There are a

few housing estates which try to conserve water by making use of grey or rain water but these are scarce.

Table 5. the ratio of building orientations (unit:%)

Case	south	south-east	south-west	east and west
Gwachon lowrise	38	21	20	21
Bundang highrise	0	**34**	**63**	**0**
Bundang low-rise	**73**	**0**	**0**	**27**
Jungdong highrise	50	0	0	**50**

4.3 Assessment of the ecological situation

The method used for this assessment is the Cross-Sectional Method.4 Meanwhile, the absolute numerical values of the measurements were standardized to make comparative analysis possible. The equation of the standardization is as follows.

- $Zi(Z\text{-}score) = \frac{Xi-X}{sx}$ (Mean=l, Dispersion=l)

Zi : Standardized score of i
Xi : Size of X

Table 6. The standardized results of the ecology survey

		Bundang highrise	Bundang lowrise	Gwachon lowrise	Jungdong highrise
Distance to water biotop		56.57	76	75.45	25.85
Area of water biotop		0	0	0	0
Distance to natural green		59.64	56.07	64.99	0.75
Distance to park		13.5	73.5	63.25	17.25
Ratio of green space		24.77	56.75	91.32	22.77
Ratio of natural conservation area		**0**	**0**	42.66	0
Biodiversity	Birds	0	23.28	92.77	23.28
	Insects	40.64	12.54	85.1	43
	Amphibia	0	0	94.4	0
	Fishers	45.9	61.07	76.58	0

Among the four housing estates, the Gwacheon lowrise shows the highest biodiversity because there is a large conservation area including forests, hills as well as the largest green spaces. Moreover, there are green footpaths which act as good ecological corridors and are connected with the adjacent forests and streams, and enable wild animals to move freely.
Meanwhile, the outdoor conditions were geneally so dry, due to the lack of water features such as ponds and streams, that very few animals survived.

5. Dicussion

5.1 Land use

Residential density is important in sustainable human settlements because it affects the equilibrium between development and environment. The density of Korean multi-family

4. This method is focussed on the special time. The assessment was done From June 15 to July 30 with Environmental Ecology Research Lab. in Seoul National University.

housing estates is too high to achieve sustainable environments. Therefore, it is important to find a proper density of residential developments for sustainable human settlements.

Table 7. Residential densities of sustainable housing development projects in Australia and Korean cases

Density (units/ha)	15	25-50	100	250	500
Development Cases	*Australian detached houses	•Mawson lake sustainable development (Australia)	• Halifax ecocity (Australia) • Gwacheon lowrise	• Jungdong highrise	•Public highrise housing in Korea

In the above table, the residential density of the Halifax ecocity is very similar to the Gwacheon lowrise which is most preferable among the Korean housing estates surveyed. It means that the Gwacheon has a social sustainability as well as an environmental sustainability. Of course, economic sustainability is very important in a residential development, but the Halifax ecocity project has over 210% volume ratio which is similar to the density of recent developments in Korea. Hence, 100units/ha seems to be the sustainable density in Korean multi-family housing development.
Next, a natural conservation area is the core element for ecological environments and enables plants and animals to flourish. The Gwacheon lowrise, which is a rare example of an estate with a large conservation area, has shown a higher degree of biodiversity in this survey.

5.2 Transportation system

The main commuting method in Korea is private cars which emit various pollutants while costing a lot in energy, money, and time. Catering for this kind of transportation system means that roads in the newtowns of Korea are very wide for the convenience of car traffic while walking and cycling are usually unsafe and uncomfortable. This system is unsustainable for the future because it contributes to global warming, air pollution as well as the depletion of fossil fuels in several decades.
Therefore, an environmentally friendly transportation system which is focussed on public transport in connection with shuttles, cycling and walking, should be introduced in residential developments. Also, an integrated land use and transport planning policy should be encouraged at the town planning stage. For example, high-density housing must be located around a central area to heighten accessibility, reducing both travelling distance and the need to use a car or transport in general.

5.3 Energy

In the traditional housing layout, the layout to the south was a key design element in Korea. But nowadays it is very difficult to keep south facing orientation because of block-type layout, which can raise development density, was -become very general in Korea recently. Moreover, there is no legal or institutional system to measure and enforce proper daylight standards. Therefore, the possibility that there are housing units without any direct sunlight ,especially in the winter season is very high
Solar radiation is a infinite and renewable source of energy which can be easily obtained at a cost. Hence, in housing planning, use of solar energy should be encouraged by a legal or institutional system.
Moreover, a system using grey or rain water should be promoted to save water resources.

5.4 Natural Resources

At first, the critical problem is that it is too dry because there is no surface water resourses in the housing estates. Therefore, the survival of animals is very difficult while amenity and comfort is very low. So, it is essential to conserve existing streams, lakes, reservoirs, and ponds, while collecting water and creating water biotops is important.

Another issue is to establish a water economy system, namely, a system that uses grey water and rain water. For this aim, water tanks and reservoirs can be considered as a tool both to conserve water and make a water biotop.

Meanwhile, the next important issue is to preserve features such as forests, hills, and wet areas, which form the core for ecological habitats in residential developments. Conserving existing green areas is critical to maintain the previous ecological condition. Therefore, an institutional system should be introduced to keep the natural biotops.

Moreover, a green network as an ecological corridor in a housing estate and between housing estates and adjacent biotop has a very important role in enablinging animals to move and so to enhance biodiversity.

Finally, the biodiversity of the housing estates was very low because biotops, which enable the survival of plants and animals, were very few and very little. Hence, a variety of biotops should be introduced by a legal or institutional system.

6. Conclusion

As a result of the above research, a direction is proposed for policies and institutional systems leading to the development of more sustainable human settlements.

They are the density guideline which this research suggests at 100 housing units/ha to maintain the environmental sustainability; a conservation law for natural resources in residential developments; an environmentally friendly transport system which includes a public transport system and cycle-routes; a proper daylight standard; a legal instrument which enables developers to introduce various kinds of biotops, ecological corridors, and a green network.

Next, a comprehensive planning policy including land-use, transportation, and energy use should be introduced to reduce the demand for transport, to save energy by carefully considered layout and orientation, and to preserve natural resources through the planning process. For example, high-density residential developments in central areas and also housing around places of work outside the central area can be encouraged to decrease the need for the use of a private car.

Finally, higher pricing of fresh water is important to introduce a system which uses grey and rain water in housing estates. Also, the government can adopt a policy giving priority to residents who wish to live near their places of work.

Referance

1. Kyu In Lee, Jae Joon Lee, Soo Ho Oh, Seon Young Jang (1997), Policies and systems for the development of sustainable human settlements, Korean Ministry of Construction and Transportation
2. Kyu In Lee, Jae Joon Lee, Kyung Hee Hwang, Ki Soo Kim (1996), A model development of environmentally friendly housing estates in Korea, Housing Research Institute, Korea National Housing Corporation
3. UNCHS (1996), the Habitat Agenda and the Istanbul Declaration, Istanbul
4. Korean Ministry of Environment (1995), Annual environmental statistics report
5. Urban Ecology Australia Inc. (1993), The Halifax Ecocity project, the center for urban ecology
6. The Multy Function Polis Development Corp. (1997), The Mawson lake development
7. Economic Commission for Europe (1996), Guidelines on sustainable human settlements planning and management, United Nation
8. Girardet, Herbert (1992), The Gaia Atlas of Cities, Gaia Books Ltd
9. WCED (1987), Our Common Future, Oxford : Oxford University Press
10. Building Research Institute (1996), A guideline for energy conscious urban planning

Procurement and sustainability in construction industry:
Tendering for durable relationships with process and projects

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Abstract
In the present construction industry clients increasingly seek for real value-for-money. This results in a stronger competition between contractors, preparing their bids for projects, e.g. by tendering-procedures. In addition to that effect, several governments are highlighting the issue of sustainability in their building-regulations. That means in much cases a stronger need for efforts on using sustainable building materials and systems. However, these issues seem to result in higher construction costs, which may be ineffective for the competition in the building market.
But is the need for sustainability really a cause for increasing building costs? For the short term it may be so, but for the long term these developments may even result in a more effective and efficient way of designing, preparing and realizing building projects. And not only for these aspects, but also for the periods of use and re-use of the building, these efforts can be useful: The client gets a building which is more sustainable. That means in particular that the building inhabits more durability "to survive" the period of use and even re-use, and it gives less risks for influencing its environment and inhabitants negatively.
This paper analyses some of the mentioned aspects about sustainability, especially with regard to the role of governmental regulations and the relationship between clients, contractors and architects. Recommendations are made for how these aspects could and/or should influence the procurement of construction-processes at one hand, resulting in realistic lower construction-costs at the other hand.
Keywords: architects, clients, construction process, contractors, governments, regulations, relationships, sustainability.

1 Introduction

Looking at the construction process nowadays, one can imagine that the activities generally used are being divided into different more or less sequential phases. Independent of the way of organising the construction process these phases can be distinguished into the following list [SBR, 1992]:

(1) Initiative;
(2) Design;
(3) Elaboration;
(4) Realisation;

And in addition to them, regarding e.g. long-term scope and building life-cycle:

(5) Use and/or Re-use.

Of course there can be some differences into the ways of defining these phases, but in general these are accepted parts. In addition to the mentioned construction process, there are several developments, which are influencing the way of working. A few categories with a some of these influences are e.g.:

(a) Procurement:
- *Integration of designing and construction activities;*
- *Partnering/Alliancing;*

(b) Involved parties:
- *Claiming attitude of clients;*
- *Increasing role of (small) sub-contractors;*

(c) Process environment:
- *Changing role and contents of building regulations/ codes;*
- *Need for lowest price for best quality (still in this sequence).*

These influences are in most cases the result of an important goal from much clients: Lowering prices, and improving quality. Thus, more emphasis on efficiency and productivity is necessary then. In addition to the aspects mentioned above, there can be seen another actual important development in the construction industry: The need for more sustainability into the whole construction process. And this need is not specifically initiated by the private clients of the construction industry, but in much cases by the governmental institutions (although also they are clients, when they procure building-projects, etc.); these demands are national and international translated into regulations, building codes etc. Just like the building procedures they differ e.g. throughout Europe and also more globally [Cooke and Walker, 1994].

Even neighbour-countries like France, Germany, Italy, United Kingdom and The Netherlands do have large differences according technical and organisational aspects in construction industry [Bollmann et Vincent, 1993; Garaventa e Pirovano, 1994; Tij huis, 1996; 1997a]. The existence of (multi)cultural differences play an important role in these aspects [Sanders en Neuijen, 1987].

The situation mentioned above results in the fact that especially the private clients in the market cannot influence effectively these changing and adaptation of regulations; not on an international scale but even also not on a national scale. And e.g. contractors and architects also can't do it in a strong way.
Thus, rising the construction costs, resulting in a higher construction price for clients, seems a logical reaction, but may not be the real solution for the future way of incorporating sustainability into construction projects. Especially not when regarding to the need for lowering prices into competition and improving quality. But what to do then when these stronger need for sustainability really rises the construction costs nowadays?

2 Rising demands for sustainability: Some viewpoints

2.1 General

Taking into account the developments for stronger incorporating sustainability into construction industry, it is interesting to see how the main parties involved in the construction process are dealing with it. In the following part some viewpoints are being described according practice and recent literature, for especially the following distinguished main parties in the construction process:

(1) government;
(2) client;
(3) architect;
(4) (sub) contractor.

It is a more or less generalized way of looking, but it tries to give a brief sort of state-of-the-art viewpoint from parties involved to the subject of sustainability in the construction process within construction projects. This may lead to discussion and/or rethinking the aspect of sustainability in procurement and construction industry.

2.2 A governmental viewpoint

When introducing sustainability-needs in the national building regulations ("Bouwbesluit") it was of course not the goal to rise the construction costs. At least not in the long-term periods of the building life-cycle. And that is an important point to look at: When introducing sustainability needs it has and/or should have especially a long-term scope.

Some examples are e.g.: Introducing highly-efficient heating systems are quite expensive when installing them, but the optimization in the use of produced heat results in the reduction of the use of liquid natural gas over a long period; the use of European timber wood reduces the use of tropical timber wood, which reduces the damage to specific threatened ecosystems; etc.
In general, direct damage to ecosystems and landscapes are often one of the most important threats to our environment. Therefore the Dutch Ministry of Housing, Regional Development and the Environment sees (the lack of) biodiversity and space as an important core of the problems surrounding sustainability in especially a long-term period [Boer De, 1995].
The above remarks also imply, that implementing sustainability in building regulations should not only be reduced to one or some countries, but should become a general policy for all countries, as worldwide as possible.
This is meant not only for the fact that e.g. "polluted air is blowing around the world across national borders", but also that it makes it easier to export and import several building products, which may be used everywere according their sustainability aspects. But regional and (inter)national economic reasons will still play important roles in these cases.

2.3 A clients' viewpoint

When a building is being designed, planned and realized, a client may expect that the professional partners in the construction industry will take care of a certain way of using sustainable products, working methods, etc. But when it immediately means higher construction costs, they may think it unnecessary to incorporate sustainability in their projects. At least this seems the case when the client has a short-term scope; and many clients seem to have such a scope. This means that it is quite difficult to stimulate clients for demanding sustainability in their projects, when it costs them money.
An effective way is in much situations the economic approach: Give the clients a certain way of subsidizing, when they invest in sustainable items. Especially for highly sophisticated products which are not specifically general demands according the present building regulations (e.g. solar and wind energy, etc.) this can be a serious stimulus. For some more general techniques (e.g. improved insulation, etc.) this won't be really necessary, while the market prices are lowering for these products, resulting into lowering construction costs.

From the examples described above, an important point can be derived: When not introducing generalized upgraded building regulations according sustainability, the "market" for them will stay quite weak, while nearly none of the clients is asking for it; this results in quite high costs. Therefore, stimulation of new sustanability-techniques and products, e.g. by introducing (partly) subsidized programmes, can be an effective means for integration in construction-products and projects.

These stimulating subsidized programmes have to be scaled down when the "market" becomes big enough, resulting in increasing competition and lowering construction costs and prices.
Another option is e.g. the use of incentives [Peeters, 1993]. That can also be a way of stimulating sustainability in construction projects; e.g. when results/performances are according the defined wishes/specifications, a sum is being paid back by the client to the (sub)contractor. But, as **De** Boer describes it, it still stays important in most situations that the client "holds the bridles" when initiating a building project [Boer De, 1997].
In addition to that: Governmental organizations are important clients in the construction market, so they will also still try to keep some hold of the construction process. Maybe that "having interests on both sides of the table" could be one of the important reasons why "deregulation" seems to be a difficult development in the construction industry.

2.4 An architects' viewpoint

When preparing the design of the construction project, it is necessary to use an actual list of demands. Thus, the client must seriously know what he or she wants. But sometimes clients can not really describe their wishes clearly, but only have some more or less "vague expectations". Especially then the architect plays an important role: He has to translate these expectations into a list of specifications, leading to a "constructable"design. At least, it has to be according the building regulations, while he has the duty to add his experience and expertise into the specifications and design. Doing so, the architect (or the "designing discipline", as e.g. a member of a contractor's design and build team) is one of the first parties in the construction process, who can add sustainability in a construction project. And that opportunity they will be using increasingly.
In the Netherlands e.g. there have been procured recently officially specific experimental projects, in which certain more or less sophisticated sustainable aspects are incorporated. Some features like specific installations and materials are e.g.: Solar heating, rainwater-toilets, re-used concrete and brick aggregate, etc.

It may be clear that the role of the designing architect will be an important one regarding to the used specifications etc. in the field of incorporated sustainability. On the other hand, one has to be realistic, and not only focus on "alternative ways" of design-concepts. Also in quite "normalized" ways of recent design concepts there can be a highly degree of sustainability, e.g. : certain sustainable concepts like reusable building components, *'low energy consumption" production processes, etc.
Thus, combining these features and activities, the result can be a cost-efficient building project, looking within the long-term scope. Although the initial costs may be some higher in the present, caused by sustainability-efforts (like e.g. extra costs in the Netherlands for preparing the "Energy Performance" -EPN- calculations [BNA, 1997]), the costs of use (e.g. energy-consumption) and re-use can be lowered then in the near future. When looking to costs for sustainability with regard to the influence of the building to its environment, methods like life-cycle analysis (LCA) are quite widely used.

But as Beetstra described, a broad environmental assessment of buildings is not possible with LCA, at least for the time being [Beetstra, 1996]. At least in addition to the above aspects, as it is in much cases: For a good building project you need besides a list of specifications, good design and efficient building activities also and especially: Good clients; people with a (long-term) scope and viewpoint.

2.5 A (sub)contractors' viewpoint

The implementation of sustainability in construction process not only influences the use of products, but also the working methods in the process. As a recent article describes it, the rising of sustainability (resulting in e.g. upgraded environmental regulations) is an important reason for rising the construction costs and prices. Especially in the case of using construction equipment (maintenance, fuel, specifications) this means e.g. in the region Amsterdam in 1998 an expected increase of circa 6 percent since 1997 of the costs for only the building-site. Added to the rising of the engineering costs etc. (an expected increase of circa 3,3 percent) this results in an expected increase of the total construction costs with circa 2,1 percent for 1998 [Cobouw, 1997a]. And e.g. especially in (in-town) areas where there has to be demolished before starting new construction projects, the costs will rise quite high: Demolished material cannot be “simply thrown away”, but has to be re-used or to be cleaned, etc. As e.g. suppliers already have initiatives for recycling their products after removing/demolishing them from the used building projects. The recycling initiative for polystyrene building products like insulation is an example for this, resulting in e.g. new polystyrene building products [Cobouw, 1997b].

For contractors this means not only looking to their clients and markets, but also and especially to seek for their core-competence [Huovinen, 1996]. The emphasis in competition is especially on (the performance of) the “end-product”. This means that delivered performances during use and/or re-use of the building projects are getting most important. Combining this with the emphasis on e.g. Build-Transfer-Maintenance (BTM), the long-term scope will become of increasing importance [Tijhuis, 1997b]. This should include the use and re-use of the building (and in addition to that e.g. demolished building materials, etc.). Yet, nowadays it will not really be succesful without incorporating sustainability. So it is a real challenge to incorporate it into projects.

3 Conclusions and recommendations

When only looking to sustainability as a the cause for rising construction costs and prices, it will not really become a general accepted way of working.
Like already can be seen in practice, it is possible to incoporate it into construction projects when there is a right stimulus for using it. This stimulus can be e.g. an “immediate incentive”, like subsidizing for clients. Yet, this will not be a real solution, while these incentives should only be used to stimulate the “market” in the beginning.

Decreasing incentives should be compensated with really lowering construction costs. As e.g. a regional governmental client recently investigated the possibility of long-term relationships with groups of contractors for realizing their building-projects: Working within a more or less standardized concept (a so called "bouwstroom") could then reduce the overall construction costs including maintenance, within the demanded quality-level [Provincie Zuid Holland, 1997]. Already in the early sixties this way of working was being used quite regularly, although nowadays there should be much more effort in keeping the individual quality as high as possible. Long-term "flexibility and maintainability" for keeping the projects upgraded for the market and sustainable for its environment are important issues then. A strongly collaborative organization will be necessary then for being succesful in these fields.
These viewpoints can give a good stimulation for integrating sustainability in projects, but still very important will be that the client must accept it; not only now, but also in the near future. A good concept and seriously attention to the project life-cycle can stimulate this. Working on durable relationships within construction teams should then be a logical part of the process. The creation of e.g. alliances could then be an effective way of offering cost-efficient solutions to clients [Badger and Mulligan, 1995]. But the use of integrated product-process concepts plays an important role then [Tijhuis, 1997c]. This can rise the efficiency of the work, and gives clients a clear focus on the "added value" for their projects. Sustainability can be and should be such a value.

4 References

Badger W.W. and D.E.Mulligan (1995) *Rationale and Benefits Associated with International Alliances;* article in: Journal of Construction Engineering and Management; Vol. 121, No. 1; pp. 100-l 11; March 1995; American Society of Civil Engineers (ASCE); New York.

Beetstra F. (1996) *Building related environmental diagnoses - Towards a broad an practical methodfor a comprehensive sustainability analysis of a building, including its sites 'aspects on the basis of a limited set of abjectively computable indicators;* article in Journal: Heron; Netherlands School for Advanced Studies in Construction; Vo1.41, No.3; pp.161-174; Delft.

BNA (1997) *Standaardvoorwaarden 1997 - Rechtsverhouding opdrachtgever-architect;* Association of Dutch Architects/Bond van Nederlandse Architecten (BNA); May 1997; Amsterdam.

Boer De E.K. (1997) *"De teugels in handen...... op weg naar een beter bouwproces"*; inaugural lecture-notes; University of Twente - Construction Technology and Construction Process; October 1997; Enschede.

Boer De M. (1995) *Milieu, ruimte en wonen*; Dutch Ministry of Housing, Regional Development and the Environment (VROM); Den Haag.

Bollmann M. et J.Vincent (1993) *Construction et Pratiques - L 'example de la France et de 1'Allemagne / Bauen in der Praxis - Das Beispiel Frankreichs und Deutschlands;* Centre Scientifique et Technique du Batiment (CSTB) en Ecole de=Architecture de Strasbourg; Plan Construction et Architecture (PCA), Paris.

Cobouw (1997a) *Bouwkosten stijgen met ruim t-wee procent*; article in: "Cobouw"; magazine; 26 November 1997; Ten Hagen & Stam BV; Den Haag.

Cobouw (1997b) *Reststoffen-inzameling polystyreen haalbaar;* article in: "Cobouw"; magazine; 5 December 1997; Ten Hagen & Stam BV; Den Haag.

Cooke B. and G. Walker (1994) *European Construction - Procedures and Techniques;* Macmillan Building and Surveying Series; The Macmillan Press Ltd., London.

Garaventa S. e P.Pirovano (1994) *L=Europa dei progettisti e dei costruttori - Procedure e operatori delle costruzioni in Francia, Italia, Regno unito e Repubblica federale tedesca;* Architettura collana diretta da valerio di battista; Masson S.p.A.; Editoriale ESA; Milano.

Huovinen P. (1996) *Competence-based contracting business;* Institute of Construction Economics and Management; Helsinky University of Technology; Espoo; CIB- W65 Symposium: The organization and Management of Construction; Proceedings: Vol. One, Managing the Construction Enterprise; pp.208-217; Eds.: D.A.Langford and A.Retik; Strathclyde University, Glasgow; 28 August-3 September 1996; E & FN Spon, London.

Peeters W.A. (1993) *Incentives in Government Procurement Contracts;* article in: >Public Procurement Law Review=; journal; Vo1.4; pp. 197-209; Sweet & Maxwell Ltd.; London.

Provincie Zuid-Holland (1997) *Goed bouwen, Goedkoop wonen - Nieuwe wegen naar verlaging van stichtingskosten;* report; Provincie Zuid-Holland, Projectgroup "Goedkoop Bouwen"; Maart 1997; Den Haag.

Sanders G.J.E.M. en B.Neuijen (1987) *Bedrijfscultuur: Diagnose en beinvloeding;* Van Gorcum; Assen, Maastricht.

SBR (1992) *Types of construction organization in the Netherlands;* Tijhuis W., G. J.Maas and D. Spekkink; University Centre for Building Production, Eindhoven; EGM-Research, Dordrecht; Stichting bouwresearch, Rotterdam.

Tijhuis W. **(1996)** *NEDU-Bouw - Aspects of Dutch and German construction processes;* poster-presentation and proceedings; Conference: From Materials to Building Structures; 25 and 26 April 1996; Ed.: G.J.M. van Mier and L.J.Sluys; Netherlands School for Advanced Studies in Construction; June 1996; Delft.

Tijhuis W. (1997a) *Duitsland - Overheidsmarkt in Duitsland;* Standard Guide, series of publications: Europese Overheidsopdrachten - Praktische handleiding voor Nederlandse bedrijven; Part II-D, pp.D3.1 O-1 to D3.10-7; several authors; Henneman K., Bossen R.I, etc.; Ten Hagen & Stam BV; Den Haag.

Tijhuis W. (1997b) *Contractors offering total packages to clients: Changing culture of contractual relationships;* University of Twente - Construction Technology and construction Process, Enschede; CIB-W92 proceedings: Procurement: A key to innovation; publication 203; pp. 751-760 and 851-852; Eds.: Davidson C.H. and T.A.Meguid; IF Research Corporation, Universite de Montreal; 20 -23 May, Montreal, Canada.

Tijhuis W. (1997c) *General contractors and Fenestration business: Professional partners or opponents?;* keynote-speech; congress: The Future of Fenestration; Berlin, 30 April-3 May 1997; FAECF - Federation des Associations Europeennes des Constructeurs de Fenetres; Frankfurt am Main; WT/Consult BV - Consultants for (inter)national construction process and project development, Rijssen; University of Twente, faculty of Technology and Management, Enschede; Congress Report; pp. 163- 168; Eds. FAECF, Frankfurt am Main.

Land planning evaluation: The new Tuscan Planning Act N. 5/1995

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Abstract
This paper examines the new land planning act of Tuscany which can be considered one of the most innovating planning act. For instance, it states that the whole land planning activity carried out in the region must pursue the leading goal of the sustainable development. The paper focuses on one of this innovating aspect, namely the evaluation of the choice made in the plan and describes the structure of evaluation system established by the Tuscan legislator both under the organisation aspect and the contents of evaluations.
After three years of validity it is possible to make some remarks on the performance of this evaluation system, which is not highly satisfying, because of the inefficient behaviour both of the bodies charged of it application and professionals
Keywords: environment, evaluation, land planning planning law

1 Introduction

Evaluation is rather an unusual activity in land planning, but the growing interest in environmental issues is stimulating its use.
Most of the experiences in land plans evaluation concern structural plans at the various levels and sectorial plans, but there is no great experience in the evaluation of town master plans. In fact, in this field there are very few reliable records, technical and professional skill is not widespread and, above all, local administrative and technical staff have no familiarity with this kind of problems.
Therefore, the new regional planning act of Tuscany can be considered an interesting occasion to see how evaluation can be taken into consideration in plan-making and to highlight some problem in its management

2 The Tuscan planning act n. 5/1995

The Tuscan Regional Act n. 5/1 995 "Rules for Land Management" [1] is the tool by which the Tuscany Regional Government intends ta govern the regional territory in the next future.
Because of its innovating contents, this law has become one of the most important reference for many Italian regions and for the most interesting bill of the land planning reform at national scale [2].
This law is based on these innovating principles:

- Sustainable development as the main strategic goal to be pursued by all land plans in the region. Sustainable development is defined by the law as " the development which assures equal potentiality of increasing welfare for all citizens and safeguard the rights of next generations in using land resources." Natural resources i.e. air, water, soil fauna and flora), towns and settlements, landscape, historical sites and buildings, technological and infrastructural systems constitute the land resources. Previously, land plans followed vague principles of efficiency, effectiveness and equity.
- The autonomy of all the bodies who have the right to plan the regional territory. The functional planning system is now organised in three levels:
    - the Regional Government establishes the medium and long run strategies and the general rules of planning in the regional plan (Piano d'Indirizzo Territoriale),
    - the Provinces specify these strategies and rules at their intermediate level and co-ordinate the local plans with the province plan (Piano di Coordinamento Territoriale)
    - the Municipalities apply these strategies in their master plan (Piano Regolatore Generale)

  Within this planning system, each body approves his own plan, just with the constraint of the compatibility with other plans

Previously, planning was organised according a hierarchical structure and land plans proposed by Municipalities and Provinces were approved by the Regional Parliament.

- A transparent decision process as a fundamental condition for correct planning. Social participation is essential in guiding and controlling the planning process, because of the lack of any substantial control. The transparency of the planning process is a major way to create a common knowledge. Previously, there was no interest for this issue.
- The town master plan is structured into three different but strictly co-ordinated planning tools, each of them having its specific and functional role:
    - the structure plan: which establishes the strategic issues of the municipality
    - the urban code, which governs routinaire issues
    - the integrated program of intervention which governs structural issues

  Previously, a single plan governed strategic, structural and routinaire issues.
- The compulsory evaluation of the plan. Previously, evaluation was not taken into consideration in land planning.

3 The need of evaluation

The use of the evaluation as a component of the planning process derives from these considerations [3]:

1. efficiency and effectiveness of planning choices in terms of sustainable development must be verified and demonstrated because urban planning does not include the judgement rules which allow the plan to be judged according environmental issues(a land plan can be considered a good one even if it is environmentally bad). Therefore, the planning process needs evaluation because it is not possible to judge the quality of the land plan when land resources are a major issue of the plan.
2. with the previous regional planning regulations, which followed the national ones, provinces and municipalities land plans ought to be approved by the Regional Parliament as the powers organisation in land planning were based on a centralised structure of authority. So doing, the upper rank of the hierarchy guaranteed that general interest were pursued by the plan and that its technical quality was satisfying. With the new law each body approves its own plan, without any hierarchical control. The structure of authority then becomes decentralised. In this new situation, provinces and municipalities become autonomous centres of responsibility and decision within the legal frame established once for all by the law. With the lack of external or internal regulators (the market and the hierarchical control), there is the need to demonstrate that land plans are efficient, effective and coherent with the main goal of the sustainable development. In other words, evaluation is an offset for the self-government.

3. a socially shared common knowledge of the planning process is essential for the effective social participation. Transparency, that is pubic knowledge of the planning process , must be assured.

4 Some notes on the evaluation of plans

In planning, evaluation is mainly seen as a decision aid, its aim is to identify the best or the most satisfying alternatives using formalised methods and procedures' The importance of evaluation as a decision aid in planning for sustainable development derives from the lack of self-control within the social system with regards to the environment, together with the complexity of environmental problems, which cannot be governed through the traditional bureaucratic-administrative model of choices. Therefore choices must be evaluated [4]

As planning decisions are the result of a social calculus, in which political feasibility, technical rationality and economic considerations are mixed, the plan evaluation appears as a political event, which is a component of the political context of the decision and it enters in the negotiation game associated with these public decisions. From this point of view, the evaluation plays a complex role fulfilling three practical needs for the public administration.

The first is a material one and consists in a better management of land policies and actions through the control of their effects on the environment? on the territory and on the social system. The second has a symbolic nature and consists in giving an image of rationality to administrative behaviour, justifying its choices. The third is related to politics and concerns the support given by evaluation to the social participation.

If planning evaluation has such a political role, it must be reliable, make use of verifiable information, must be based on the scientific method and become common knowledge [5, 6,7].

5 The evaluation of the land plans according to the Tuscany Regional Act n. 5/1995

According to the TRA n.5/95, evaluation is a major activity in the planning process and indispensable for approving the plan. This rule is enforced by the articles 5 and 29 which establish that:

- the environmental effects, together with the effects on ail land resources produced by each planning choice must be analysed and evaluated
- no town expansion is allowed, if there is a possible alternative in renewal and infrastructures re-organisation. In any case, the use of new land must have positive effects on settlements rehabilitation and natural resources safeguard

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[1] Evaluation is generally defined as a scientific method, which is useful to express a judgement on the results of a policy or on the effect of an action with reference to some value. It is based on rationality and its aim is to measure results or analyse effects. Therefore, it emphasises causes and actors.

- the effects of any structural choice, which have structural effects on environment, settlements and communities, must be also examined through economic and financial evaluations.

How and when these evaluations must be carried out and the procedures of the evaluation process are established by the regional evaluation code..

5.1 The evaluation system

The evaluation system laid down by the TRA 5/95 can be describe according its functional organisation and the contents of the evaluations.

5.1.1 The functional organisation of the evaluation system

The functional organisation of the evaluation system is structured on three levels

1. The regional government level, i.e. the level of the evaluation rules. At this level, the regional government:
    - establishes the general rules and the evaluation procedures which must be carried out in land planning making, fur instance, what choice must be evaluated, when and how evaluations must be performed, who must evaluate, etc.
    - collects, elaborates and places the information needed for evaluation,
    - monitors the evaluation activity of both provinces and municipalities, encourages the spreading of evaluation sensibility among planners and professionals, co-ordinates professional training in the field and sponsors research activity
    - verifies the correct enforcement of its regulations.
2. The provinces level, i.e. the level of the evaluation guidance. Through its plan? the province:
    - converts the general rules laid down by the regional government into operative rules suitable for its territory, establishes the criteria and parameters which must be used in plans evaluation and co-ordinates the evaluation activities of the municipalities,
    - builds up the operative information system of land resources, individuating their vulnerability and reproducibility.
3. The municipality level, i.e. the evaluation operative level:
    - each municipality evaluates the actions included in its master plan according to the general rules established by the regional government and specified by its province.

5.1.2 The contents of the evaluations

The actions included in the land plan must be evaluated, not the plan itself. These actions are evaluated in regards of the specific goals of the plan and in terms of effects on land resources. The provinces establish which actions must be evaluated and the kind of evaluation needed in each case

These evaluations concern:

- the effects of an action on natural resources (impact evaluation')
- the effects of an action on land resources (impact evaluation)
- the new urban use of agricultural land (evaluation among alternatives)
- the economic and financial efficiency of structural interventions (efficiency evaluation)

6 Problems and diffkulties.

After three years and with several land plans which have been approved, it is possible to make some remarks on the performance of this law.
In fact, its first results are not exciting? because:

- the regional government has not yet accomplished some very important tasks? like the approval of the evaluation code,
- the provinces have approved or are approving their plans, but in many cases the evaluation aspect has been just touched, most of the provincial information ystem are fragmentary or not suitable for reliable evaluations, just a minority of them has fixed good evaluation parameters and criteria.
- most of the municipalities which have approved their structural plans, have underestimated the evaluation aspects, following the same mistakes made by the provinces.

But even those plans which have performed satisfyingly their evaluation task show important problems because evaluation still remains a side issue in the planning process,and not a structural component as request by the regional legislator'.
The unsatisfying performance of the Tuscan evaluation system has many reasons:

1. the widespread unfamiliarity of the evaluation activity among administrators and planners, so that intuitive and poor evaluations are prevailing,
2. the deficiencies of the provinces in leading the evaluation activity among the municipalities an co-ordinating the evaluation system at the operative level
3. the slowness of the regional government in performed its leading tasks., so that the lack of the regional evaluation code has negatively effected the functionality of the system, the right political choice of gradually introducing evaluation in the planning process has been often ill interpreted by local planners as low interest for this issue: the administrative and technical structure is inadequate.
4.

[2] The aim of this impact evaluation is to clarify choices in regards to the goals of the plan and to verify the effects of choice in regards of the general strategy towards land resources. Therefore, it cannot be confused with the standard environmental impact evaluation. In fact. standard EIE must verify the compatibility of a project with an environment situation, considered satisfying, therefore it is related to projects, ii 'needs detailed information which are not disposable at the planning level. it is only generically goal-oriented and, above all, it is too expensive to be employed in all the choice made in the plan.
[3] See, for instance, the structural plan of Pisa, which is one the most correct application of the law.

This situation has some important implications, the most important of which concerns the use of evaluation in the planning process. In fact, evaluation has mostly been used as a mean to justify the choices already made in the plan, that is, the legitimisation role of the evaluation has been preferred in comparison with its main task as a decision aid. This misuse is creating conflicts between analysts, political decision-makers and planners, because, when the analyst evaluates an already made choice (that is, when his main task is nothing but the legitimacy of the plan) he acts as a final judge of political and technical choices. Therefore, evaluation can be seen as a constraint to the political and professional autonomy of the decision-maker. Then, there are the risks either of rejection and manipulation of the evaluation and of potential conflicts.
Potential conflicts are also originated by the structure of the evaluation system itself The problem is which aspects must prevailing in plan making, i.e. if the environmental aspects are more important then the social, economic and functional ones. This is a main latent problem in many land plans. Even if the regional legislator has given a clear definition of sustainable development which does not allow bias interpretation of the weight of environment in planning, nevertheless, when the evaluation system markedly privileges the environmental evaluations in comparison with the efficiencv anh effectiveness evaluations, there is a confused situation which stimulates potential conflicts between partisans of the environmentalist plan and partisans of the other interpretation, thus giving which has a bad image of evaluation in planning.
The last remark concerns the behaviour of the bureaucratic and professional structures. Here it appears a large tacit resistance to the enforcement of the evaluation in land planning that has two main causes. From one side, the enforcement of the law requires a deep change in the consolidated professional capacity, which needs intellectual and physical efforts. From the other side, the most of planners do not have the culture and the technical skill to manage the evaluation aspect of planning. Therefore, disinterest and fear to loose the control of the whole planning process are widespread, which have brought either to ignore the evaluation or to produce very poor evaluations.
Concluding, even if the TRA n.5/95 is a verv important step towards the use of evaluation in the planning process, there is still a long way to do before reaching the goal.

References

1. Regione Toscana-Giunta Regionale (1995) *Legge regionale 16 gennaio 1995, n.5 "Norme per il governo del territorio"*, Firenze.
2. Istituto Nazionale di Urbanistica (1997) *La nuova legge urbanistica. Indirizzi per la riforma del processo di pianificazione della città e del territorio*, mimeo.
3. Bentivegna V. e Berni M. (1966) Introduzione alla valutazione dei piani urbanistici secondo la LR 16/01/95, n.5, Regione Toscana-Giunta Regionale, *Il sistema della valutazione nella legge regionale 16 gennaio 1995, n,5*, Firenze.
4. Bentivegna V. (1997) Limitations in environmental evaluation, in Brandon, P.S., Lombardi P.L. and Bentivegna V. (eds) *Evaluation of the built environment for sustainability*, E&FN SPON, London.
5 Bentivegna V. (1966) Il contributo della valutazione alla razionalità e alla legittimazione del piano urbanistico, *Urbanistica, I.*
6 Monnier C (1987), *Evaluation de l'action des pouvoirs publics*, Economica, Paris.

7. Rangeon F. (1993) La notion d'évaluation, in Rangeon F. *L'évaluation dans l'administration*, Presses Universitaires de France. Paris

ALTERNATIVE DISPUTE RESOLUTION: THE QUEENSLAND BUILDING TRIBUNAL

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Abstract
In 1992, the Queensland Building Tribunal was established with the specific goal of obtaining quick, inexpensive and simple resolutions to building disputes by means of mediation and/or tribunal hearings instead of the more usual forms of arbitration or litigation. This paper describes research aimed at gauging the success of the Tribunal in achieving its goal.

Two postal questionnaire surveys were carried out, one being for those who had resolved their disputes through the mediation process and the other for those who had taken the matter to the Tribunal's hearing process for a ruling by determination. Out of 168 questionnaires despatched, a total of 61 completed forms were returned and analysed. The results are described under four headings (1) fairness and impartiality, (2) formality and expediency, (3) credibility and public awareness, and (4) commercial reality.

The majority of those surveyed thought the mediation process to be sufficiently impartial, expedient, informal and knowledgeable. In contrast, the hearing process, as expected, was perceived to be less expedient and more informal and intimidating. There are significant areas of concern over the absence of 'of right' legal representation and the reasons for settlement at the mediation stage. It is suggested that mediators receive some training or at least some guidelines are issued on the mediation process, that "duty lawyers" are made available for consultation with the parties, and that mediators may, with common consent, act as adjudicators when circumstances require.
Keywords: Arbitration, dispute resolution, mediation, Queensland Building Tribunal, questionnaire survey.

1 Introduction

The "Home Building Review", was established in 1990 by the Queensland Government in response to the failure of the Queensland Builders Registration Board to resolve matters relating to building disputes. One of the major recommendations was that "there is a need for a quick, inexpensive dispute resolution process with simple procedures [and that] for this purpose a domestic building tribunal should be established to resolve all the disputes between parties in the home building industry" [1]. This recommendation was realised the following year under the Queensland Building Services Authority Act with the establishment of the Queensland Building Tribunal, whose exclusive duty it is to hear and determine matters relating to domestic building disputes. Under the Act, the Queensland Building Tribunal may appoint a mediator or mediators to endeavour to achieve a negotiated settlement of a domestic building dispute and the Tribunal has opted to use mediation as a precedent wherever possible in the settlement of disputes.

The process is simple enough. Upon a domestic building dispute becoming evident, a party may make application to have the Tribunal hear the matter. The applicant must then deliver a copy of the application form to the respondent who, in turn must notify the Tribunal's Registrar and the applicant of his address for service of documents. The Tribunal then proceeds to arrange a mediation meeting between the parties and issues a notice of mediation to both the applicant and the respondent. The mediation is then conducted at which time both parties are brought together with a mediator to attempt to reconcile the parties and settle the dispute. If an agreement is reached, the mediator reports on the terms of such agreement or settlement to the Tribunal. The Tribunal may then make a determination in terms of the settlement, and may make consequential orders or directions on the basis of the mediator's report. Should no agreement be reached, the Tribunal directs that statements be filed by the parties and all other witnesses. The Tribunal then directs that a pre-hearing conference of directions hearing be held at which time the Tribunal inquires as to whether or not the parties have reconciled or would wish to rediscuss the matter with a mediator. If the parties advise that no reconciliation has occurred, the Tribunal allocates a date at which time the matter is heard and the dispute determined. A member conducts the hearing at the appointed date and, based on the evidence, makes a determination in respect of the dispute.

The width of the Tribunal's power is extraordinary and its duties similar to that of a court. In the exercise of its jurisdiction., the Tribunal may exercise any one or more of the following powers:

- order the payment of a monetary sum to be owing by one party to the other;
- award damages, including exemplary damages, and damages in the nature of interest;
- order restitution;
- avoid any unjust contractual term or otherwise vary a contract to avoid injustice;
- avoid a policy of insurance under the statutory insurance scheme;
- order rectification of defective or incomplete building work; and
- award costs.

Under this Tribunal system, the mediator has the protection and immunity of a member of the Tribunal. Evidence of anything said or done in the course of an attempt to settle a domestic building dispute is not admissible in any proceedings before the Tribunal or in related proceedings. If a dispute is settled, the mediator reports the terms of the settlement to the Tribunal and the Tribunal may make a determination in terms of a settlement, and make consequential orders or directions. There is however, under the Act, no clear definition of who may be a mediator, the process of mediation or of what mediators may do. The minimum qualifications of the mediator are not specified nor is the person identified with the authority to appoint mediators.

Perhaps the most controversial aspect of the system is that the use of arbitration is specifically excluded as a means of dispute resolution. In Australia, where such issues are high on the political agenda, the specific exclusion of one particular industry group is tantamount to unfair discrimination. The main problem is not that mediation is included but that arbitration is specifically excluded under section 61 of the Act [2]. The reasoning behind this rather dramatic measure is to be found in the Home Building Review Report, which condemned the then current practice of arbitration as (1) lacking impartiality, (2) being prohibitively costly in both money and time, and (3) abusive of procedures. The extent to which this statement is actually true is not known at this time.

2 Survey questionnaire

In order to measure the degree of 'success' of the Queensland Building Tribunal mediation system of dispute resolution, some kind of feedback from its participants is necessary. In other words, the perceptions of those parties who have actual experience of the Tribunal and its proceedings need to be studied. For this purpose, a survey questionnaire was undertaken.

The Tribunal was contacted and a total list of all applicants and respondents that had been through the system up to that time (1993) was provided to the researchers. As a result, a total of 200 potential respondents were identified. Of these, approximately 90 were contacted by telephone to gauge their initial response to being surveyed and their acknowledgment that they would complete and return a postal questionnaire.

Two questionnaires were developed - one for those respondents who had resolved their dispute through the mediation process and the other for those who had taken the matter to the Tribunal's hearing process for a ruling by determination. The questions contained in the questionnaire were aimed at establishing the level of support, or otherwise, for the Queensland Building Tribunal dispute resolution system. To keep the questionnaire simple and gain a maximum response, it was designed to be completed in no more than five minutes. This resulted in an instrument structured over two pages in a question and yes/no response answer style. The questionnaires also provided for general commentary if desired and were issued to the sample with a pre-stamped return envelopes. In the event, 168 questionnaires were issued in late June 1993. In all, 63 completed questionnaires were returned - 33 relating to the mediation process and 28 related to the hearing process.

3 Results

The questionnaire and its results are divided into four sections: (1) fairness and impartiality, (2) formality and expediency, (3) credibility and public awareness, and (4) commercial reality. These are presented below.

3.1 Fairness and impartiality

The basic component of any justice system must be that it is seen to be acting in a manner, which is fair and impartial in its operation and determination to both parties.

3.1.1 The mediation process

The basic principles of mediation as a process of dispute resolution are such that the mediator should not be able to be seen as anything but impartial, as the mediator's primary function is to get the parties talking, to direct or help them achieve a settlement by themselves, which the mediator will ratify through a statement or mediation agreement.
Discussions with a member of the Queensland Master Builder's Association noted comments raised by some builders that they had felt pressured during the mediation process in a way which they perceived to be more than simply leading.

Overall, 80% of responses (95% of applicants and 70% of respondents) thought the mediation process to be impartial. Similarly, 92% of applicants and 75% of respondents considered the mediation process to be informal. 38% indicated that they were adversely pressured by the mediator to resolve the dispute.

3.1.2 The hearing process

29% of responses believed the process not to be impartial and 40% did not believe the process to be a fair means of resolving disputes.

3.2 Formality and expediency

Action and speed in resolving building disputes are of crucial concern to all parties. Procrastination in finding agreements can cost both parties to a dispute in terms of finance, time and health. Furthermore, behavioural studies suggest that parties are more likely to resolve a dispute on neutral ground and in a comfortable, non-suppressive, atmosphere.

In terms of the mediation process, the time involved in getting the mediation started should be quite short as “the Tribunal appoints a mediator who will contact the parties to arrange a mutually convenient time and place for the mediation within 14 days” [3]. This time frame should adequately meet the expectations of the parties.

The average time from application up to hearing was four months. This would seem to compare favourably with the traditional court system, where the general perception is that a matter before the court may, and often will, take several years to be heard and resolved. Also, the formal Tribunal hearing premises are well appointed, they appear to be fresh and do not seem to have any feeling of a stuffy court setting. The two rooms involved do, however, still represent a feeling of authority with a member (judge) set to the front of the room behind a desk separated by a large space from the disputing parties and public seating at the rear.

Although parties may not have legal representation present at mediation or hearing, many disputants obtain advice or assistance in preparing their claims and responses. There have been some differences in opinion over the availability of legal representation., with the Home Building Review Report opining that legal representation should only be as of right in the matter concerning disciplinary procedures against licensed building contractors and subcontractors on the grounds that “most building disputes are not complex and do not involve questions of law . . . most are resolved upon tidings of fact of a very basic character” [1]. Cotterell, however, holds the opposite view in claiming that many disputes ". . . involve factual and legal questions” [1]. Whether or not the disputing parties should be entitled to legal representation ‘as of right’ is an issue yet to be determined. It is likely that applicants would be against legal representation due to the extra costs involved and the possibility of the representation strengthening the opposing case.

3.2.1 The mediation process

The responses indicate that the Tribunal’s mediation is meeting the expectations of customers and builder if not the groups, which represent them. As far as expediency is concerned, 95% of all the responses confirmed that the Tribunal processed disputes to their satisfaction.

3.2.2 The hearing process

38% of responses thought the Tribunal hearing process to be conducted in a formal manner. 30% of responses did not consider the Tribunal hearing to be conducted expeditiously, with the same proportion also not feeling comfortable with the surroundings in which the hearing was conducted. 23% of responses indicated feeling intimidated by the member. As expected, the respondents (100%) were more in favour of 'as of right' legal representation than applicants (12.5%).

3.3 Creditability and public awareness

In following the doctrine of natural justice, which holds that *no man shall be a judge in his own* court, it is not the practice of the Tribunal to appoint industry-based persons such as architects, engineers and builders as mediators. As a result, the majority of the Tribunal's mediators have a legal background. This naturally raises concerns over mediators' ability to quickly grasp the technical issues involved in building disputes. The Tribunal does, however, engage the use of Queensland Building Services inspectors, most of whom have a building trade or technical background, to act as mediators. The building inspectors have had no formal training in the conduct of mediation or social behavioural studies.

This situation brings into question the credibility of the Tribunal. Any institution or organisation's creditability and acceptance rests on the level of competence it demonstrates. One means of measuring the perceived creditability of the Tribunal is by gauging consumers' and builders' perception of the Tribunal's knowledge and understanding of the building industry.

A related issue is that of public awareness. One view is that the Tribunal's services should be advertised extensively so parties may realise that there is a relatively quick and cheap means of resolving disputes available. Another view is that, if the Tribunal were to actively advertise its existence, it might become inundated with frivolous disputes that are presently being resolved easily and congenially by builders and consumers. To date, the Tribunal has adopted a low-key approach and consumers and builders are likely to become aware of the Tribunal's existence only when a dispute that cannot be readily resolved by the parties becomes evident.

3.3.1 The mediation process

A large majority of responses (93%) considered an adequate knowledge of the building industry to be important while rather less (74%) thought that the mediator really had such knowledge, with 84% of responses believing the mediation process to have been an appropriate solution to their problems. 48% of responses were aware in advance of the Tribunal's mediation procedure.

3.3.2 The hearing process

64% of responses thought that the Tribunal did have adequate knowledge of the building industry. 77% thought the Tribunal hearing to be an appropriate method and 50% were aware in advance of the Tribunal's hearing procedure.

3.4 Commercial reality

The social trauma that occurs due to a proceeding before a court or tribunal is difficult to gauge as each individual approaches, and in turn is affected by, such circumstances differently. It is a fact, however, that some people will be left with a lasting emotional scar. This issue is of particular interest when considering the resolution of disputes by mediation, which offers an opportunity to settle with a minimum of time, cost and emotional expense.

Actual or expected delays in proceeding to a hearing force applicants and respondents to make decisions and agreements which they may not have made had an immediate determination been available. Such delays can be for a period of 3 months or more and the Tribunal will naturally reflect a feeling of injustice in respect of decisions, which are made by parties as a perceived imposition. On the other hand, attempting to avoid delays by pressuring premature agreements is hardly likely to be a satisfactory solution as it is justice that is being sought and not just a speedy conclusion.

Applicants and respondents views were quite different. 3 1% of applicants against 58% of respondents reached a mediation agreement because of feeling unable to handle proceeding to the hearing process. 3 1% of applicants against 67% of respondents reached a mediation agreement as a result of a commercial financial decision, ie. to avoid the costs of a hearing.

4 Discussion

One of the major findings reported here is the significant numbers claiming to have been adversely pressured by the mediator to resolve the dispute. This problem seems to originate from a lack of instruction on mediation and it would seem a set of guidelines issued by the Tribunal might help. Such guidelines should not hinder or limit the running of the Tribunal's mediation process and should not prejudice the Tribunal's role of acting independently of the individual parties involved.

That some of the responses thought the Tribunal not to be impartial is of some concern. However, it could be argued that the perception of justice on the part of the losing party would be tainted by the mere fact of the result. One way to attempt to overcome this perception is for the proceedings to be conducted in a clearer and more open manner. Another possible solution is to introduce a duty lawyer system to complement the Tribunal's services with junior lawyers providing an advisory service to both applicants and respondents on a casual basis. Such a system should be both cost effective to the Tribunal and beneficial to those parties using the proceeding through the Tribunal system.

That 23% of responses found the Tribunal to be intimidating is unfortunate but perhaps unavoidable as it is very much a part of all judicial systems to provide an air of authority, which can be intimidating to some people, especially those with no previous experience of court proceedings.

The many responses, particularly from those who had been respondents in disputes, believing that 'as of right' legal representation should be available is clearly a question of benefits and costs. Legal representation is not only expensive but does tend to extend the period of the proceedings, and the question of finance needs to be addressed if the parties are to be provided with free legal aid. Legal representation is allowable under the present system providing the member feels it justified, this option being available on a case by case basis. Alternatively, the duty lawyer system, mentioned above, may suffice in most cases.

The question of the technical knowledge of mediators is potentially very difficult to solve. Clearly the doctrine of natural justice must be regarded and yet, equally clearly, some degree of technical 'know-how' is necessary for building disputes in order that decision makers are sufficiently well informed. The first issue concerns bias and the second concerns reliability. To have the best of both worlds would seem to require at least a technical adviser to the mediator. In view of the survey results, in which approximately three-quarters of respondents felt the current situation to be adequate, there seems to be little cause for alarm as yet.

One of the main purposes of mediation is to progress disputes to a conclusion as quickly as possible. That many of the respondents are accepting a premature settlement because of the time, money and emotional risks involved in proceeding onwards, suggests that further improvements are necessary to the present system. One such improvement might be to allow the role of the mediator to be extended to adjudicator where both parties so agree. This could help in cases where there is a deadlock and no other prospects for a solution other than to continue into a lengthy and protracted hearing. Instead of the present practice of calling bluffs, a simple executive decision by the mediator should encourage the parties to act in the pursuit ofjustice rather than in avoidance of the risks involved in continuing.

5 Conclusions

The Queensland Building Tribunal was established in 1992 with the specific goal of obtaining quick, inexpensive and simple resolutions to domestic building disputes by means of mediation and/or tribunal hearing. This paper describes research aimed at gauging the success or otherwise of the Tribunal in achieving its goal.

The majority of those surveyed thought the mediation process to be sufficiently impartial, expedient, informal and knowledgeable. In contrast, the hearing process, as expected, was perceived to be less expedient and more informal and intimidating. There are significant areas of concern however over the absence of 'as of right' legal representation and the reasons for settlement at the mediation stage. It is suggested that mediators receive some training or at least some guidelines are issued on the mediation process, that "duty lawyers" are made available for consultation with the parties, and that mediators may, with common consent, act as adjudicators when circumstances require.

The results of this survey generally support the Queensland Building Tribunal's mediation process in achieving the timely settlement of building disputes. Subject to the reservations mentioned above, there seems to be no major barrier to the development of equivalent organisations and procedures in other parts of Australia or the world in general.

6 Acknowledgments

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7 References

1. Kelly, R., 1990, *Home Building Review Report*, Queensland Government.
2. Jones, D.S., 1992, *Queensland Building Services Authority Act 1991*, discussion paper, Morris Fletcher and Cross.
3. Cotterell, B., 1993, *The Queensland Building Tribunal*, discussion paper, The Queensland Building Tribunal.

Contractual systems for construction refurbishment projects

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Abstract

This paper is based on an on-going research at the South Bank University London, UK The aim of the research is to develop an artificial intelligence system for the selection of contractual arrangements for construction refurbishment projects. The paper argues that there is no substantial study in the area of procurement selection for refurbishment works. The legal framework of construction contracts is reviewed. The main characteristics of artificial intelligence used for procurement selection are highlighted. The paper then concludes that there is the need to develop an artificial intelligence system for procurement selection for refurbishment works. The benefits that could accrue from the development and application of an artificial intelligence in procurement selection are many including a dramatic improvement of efficiency in terms of the speed of reaching an informed decision, reliability of the expert advise as the system is built in with a robust expert knowledge and it provides a datum of knowledge distilled from acknowledged experts.

Keywords: construction contract, procurement selection, artificial intelligence, construction refurbishment.

1. Introduction.

The lack of guidance in the selection of contractual systems for construction refurbishment works is seen as an acute problem (Robinson 1990). Robinson (1990) also argued that "the standard form of contracts developed for new build applications have very little relevance to the complexities and diverse nature of works on exiting shells". Ferry and Brandon (1991) advised, that "the uncertainties of refurbishment work mean that it will be almost impossible, and certainly inadvisable, to undertake the (refurbishment) project on the basis of lump sum competitive tenders for works, and other more collaborative methods of procurements will have to be used - either cost-plus or some form of management contracting" (Ferry and Brandon 1991). Fellows et al. (1985) in their research report observed that while contractual arrangements and management systems designed for new-builds are used for refurbishment work, "ad hoc use of new build arrangements does not satisfy clients' criteria (in terms of project performances: time, cost and standard of completed work) well" (Fellows et al. 1985). The report observed that "the existing contract forms and tendering procedures, which are designed for new-build projects are inappropriate for refurbishment projects as they do not give sufficient importance to the time requirements" (*ibid.* p.16). Fellows et al. emphasised that "refurbishment projects require an organic form of organisational arrangement which permits flexibility in the allocation of tasks and a collaborative attitude between the members" (Fellows et al., *loc. cit.*). Furthermore the report noted that there is a high degree of mismatch between the levels of clients' control over commercial refurbishment projects and the chosen types of contractual arrangements used for construction refurbishment works. Fellows et al. then concluded that modified contractual arrangements are required to enable the clients to accomplish the required control over projects in other to optimise the project performances.

2. The gap in knowledge of contractual arrangements for construction refurbishment projects.

Several studies have been conducted, attempting to set out criteria and guidelines in choosing a contractual arrangement for a given project (National Economic Development Office 1985; Hamilton 1987; Skitmore and Marsden 1988; Love and Skitmore 1996). Expert systems have also been developed (Brandon, Basden et al. 1988; Brandon 1990, Wong and Albert 1995), to provide guidance on the most suitable contractual arrangement for a given circumstance. However, these studies do not focus specifically on refurbishment works. Furthermore many of the existing studies on the theory of procurement selection are based on a positivist research paradigm and on the rationality of the individuals making procurement selection decision. Love and Skitmore (1996) have shown that the actual selection of procurement system is irrational. A framework involving a mu&paradigm research technique and the recognition of individuals bounded rationality is identified as a better option towards procurement selection.

The problem of procurement selection in the building and civil engineering sector will appear to have inadequately satisfied the majority of construction clients. It is argued that the various procurement selection systems available are primarily concerned with the identification of a generic approach that meets the determined requirements, regardless of contractual arrangement and notwithstanding that most contractual arrangements contain characteristics of each other (Prof. Hibberd and Basden 1996). It has been shown also that the existing standard contractual arrangements arc deficient in making explicit and allocating such risks as variations and time extensions which the main contractor bears by implication (Heath and Berry 1996). Heath and Berry (1996) pointed out that there is the tendency, as the complexity of the works increases, of passing the burden of risks to the sub-contractors and creating a sub-organisational management structure that is quite different to that existing at the main level, and in turn may lead to project conflict and subsequently to clients' dissatisfaction. Therefore the problem of high project performances (which the existing procurement selection models intend to achieve) lies beyond merely matching these deficiently drafted standard contracts with project types or clients' criteria but should include matching the content of these standard contractual arrangements to the intentions of the parties involved in construction transactions.

3. Research aim and objectives

The on-going research attempts to fill the gap in knowledge by developing an artificial intelligence system for the selection of contractual arrangements for construction refurbishment projects.

The set objectives of the study are as follows:-

1. To establish the criteria used in the selection of construction procurement methods for refurbishment works.
2. To assess the impact of the standard forms of contracts on construction refurbishment projects.
3. To carry out a quantitative evaluation of time and cost of construction refurbishment projects completed with various contractual systems. Both time and cost all have a number of aspects associated with them. These aspects are broken down and form part of the study.
4. To carry out a qualitative assessment of clients' satisfaction (with regards to the standard of completed refurbishment project) in adopting various contractual systems.

4. Research methodology

This paper is based on a thorough review of literature. At the time of writing, a pilot study is being carried out by the authors to identify procurement selection criteria with reference to construction refurbishment projects. The research strategy is designed to explore the subject matter with rigour with the aim of reducing the degree of subjectivity that may accrue from a study of this nature.

5. About the legal frame work of construction contracts

There are two related types of construction contracts - first are contracts of building works, i.e., residential development, industrial and commercial developments. The building works contracts may be contracts for new works, refurbishment, and restoration. The second type are the engineering and civil works contracts- these include, the construction of civil engineering infrastructures and a variety of engineering projects such as offshore projects, dams, roads. There is no legal distinction between the building and civil engineering works contracts. Their fundamental difference is based on the nature of construction work to be carried out

The law which governs the formation of construction contracts is in principle the same with that applicable to contracts in general (May, et al, 1995). Construction contract is defined as an agreement under which a person, called variously the builder or contractor undertakes for reward to carry out for another person, variously referred to as the building owner or employer, works of a building or civil engineering character (Wallace 1995). Construction contracts are complex relational transactions- an ongoing relation which needs continual adjustment (Veljanovski 1982).

5.1 Distinction of construction contract

A fundamental distinction of construction contracts from other forms of relational and simple contracts is that as the work proceeds and become fixed or attached to the land of the owner, it progressively and irretrievably becomes the property of the owner whatever the financial rights or obligations of the party may be at the time (Van Deventer 1993; Wallace 1995). It is argued (Van Deventer 1993) that the legal rules that govern contracts in general do not adequately address the complexities and subtleties involved in construction transactions.

5.2 Standard contract forms

Most construction contracts are transacted on standard forms. In the United Kingdom, the commonly used forms for building works are the set of standard forms published by the Joint Contracts Tribunal (JCT), The Institution of Civil Engineers (ICE) conditions are used for civil engineering works. The *Federation Internationale Des Ingenieurs Conseils* (FIDIC) standard forms are mostly used for international projects of civil engineering character.

Standardisation of contracts have a number of positive attributes: it reduces transaction cost i.e., the cost of completing a transaction by providing a set risk allocation terms for use by the parties. Standard contracts have the advantage that a legal decision in one case would very likely provide a guide to disputed problems in other cases (Atiyah 1995). It is being argued that the main advantage of conditions of 'agreement' contained in the standard forms is that they have the potential for improvements (Bubshait and Almohawis 1994). Bushait and Almohawis explained that by using the same standardised conditions consistently the clarity, fairness, and efficiency of the provisions will be tested, and areas of deficiency identified and subsequently corrected. Other advantages include their familiarity to the parties which reduces the cost of drafting and prolonged review of the conditions, and that the standard-form contracts *"lessens the possibility* of *misunderstanding, undue compensation, the likelihood of change* orders, *and the occurrence of claims* or *litigation arising out of contractual performance".*

The limitation of the standard-form contracts is that they violate the 'freedom of contract doctrine': contracts being an *agreement or promises* made between parties. Atiyah (1995) argued that many of the terms of a typical standard-form contract were not agreed to in any real sense, in that they are made of a set of fixed terms with little provision for variation. The forms are sometimes drafted by one party alone, and as Bushait and Almuhawis (1994) noted, they generally favour the sponsoring organisation. In other instances neither the parties drafted the contract as in the standard-forms of construction contracts, in which case *"both parties may have only the vaguest intentions as to what the terms of their contract actually provide"* (Atiyah 1995 :18). Atiyah observed that *"quite often, these standard forms were standard throughout the entire industry, being in substance, largely agreed forms of contract which were adhered to by all firms, thus depriving the consumer of the red benefits of competing and free choice".*

In addition to the limitations referred to above, the UK standard-form contracts used in the construction sector have received a number of criticisms. They have been criticised for there obscurity. A judge ones described the standard-form construction contract as *"a farrago of* *obscurities"(Per* Edmund Davies L.J. in English Industrial Estates Corp. v. George Wimpey & Co. Ltd.. [1973] 1 Lloyds Rep. 118, at p. 126). The printed forms are characterised by ambiguities and discrepancies on the terms incorporated in them (Wallace 1995), conflict between clarity and flexibility (Hughes and Greenwood 1996). The language used in their drafting is complex and often misunderstood by the parties. They are also adversarial in nature, being based on the law of contract which on its own accord is adversarial (Jones 1994).

6. About artificial intelligence.

In recent years a new inter-disciplinary field of interactive computer systems known as artificial intelligence has emerged. Artificial intelligence is concerned with the computations that connect situations to complex, human-like actions. Artificial intelligence encompasses some intelligent behaviours such as deduction and search, learning and explanation The main applications of artificial intelligence were found in programmes for processing and understanding natural language, understanding speech, information retrieval, automatic programming, robotics, scene analysis, game playing, fuzzy logic and mathematical theorem proving, There is now an increasing application of artificial intelligence in construction related problems such as in budgeting, bid selection as well as procurement selection.
Artificial intelligence may be distinguished according to its basic approach to knowledge representation. Four approaches are identified: logic, semantic networks, frames and rule based systems.

6.1 Application of artificial systems to procurement selection.

Artificial intelligence have been successfully applied to the selection of procurement paths for general construction despite the embryonic problems that exist with any new approach. Previous development of artificial intelligence for procurement selection include the works of Wong and Albert (1995) and Brandon(1990).

Brandon (1990) developed a system which ranks various procurement paths under headings which try and define the degree of appropriateness with a built in explanation facility. By weighting both the positive and negatives arguments by a number of plus and minus signs, the consultant can be able to check on his own thinking to assess the strength of argument in a particular direction.

Wong and Albert (1995) developed a fuzzy logic artificial intelligence for contract decision making in Hong Kong. Wong and Albert identified six core criteria used in contract selection: scale of the project, nature of works, characteristics of client, time constraint, the source of materials for construction and the characteristics of building design. These factors are used to develop a decision rule that enables the selection of a procurement route that is appropriate for the circumstance.

Expert systems have been used successfully in procurement selection as Brandon(1990) and Wong and Albert (1995) have shown despite the embryonic limitations particularly the subjectivity of the systems. The results of earlier studies show the feasibility and potential benefits of developing artificial intelligence for procurement selection specifically for refurbishment works.

7. Conclusion

The paper have argued that there is lack of guidance in the selection of contractual systems or procurement path for construction refurbishment works. The paper also identified the peculiarities of refurbishment works and the need to treat refurbishment as a distinct category of construction process. The legal frame work with which construction contracts operate in the UK is reviewed and the feasibility of an artificial intelligence in the domain of procurement selection for refurbishment projects is identified.

The paper then concludes that there is the need to develop an artificial intelligence system for procurement selection for refurbishment works. The benefits that could accrue from the development and application of an artificial intelligence in procurement selection are many and they include a dramatic improvement of efficiency in terms of the speed of reaching an informed decision, reliability of the expert advise as the system is built in with a robust expert knowledge and it provides a datum of knowledge distilled from an acknowledged experts.

8. References

Atiyah, I?. S. 1995. *An Introduction to the Law of* Contract. 5th ed. Oxford: Clarendon Press.

Bennett, John, and R. Flanagan. 1983. Management Options: new directions. *Building*, 8 April 1983, 32-33.

Brandon, P.S.. 1990. Expert systems - after the hype is over. CIB 90. Pp 314344

Bubshait, A. A., and S. A. Almohawis. 1994. Evaluating the general conditions of a construction contract. *International Journal of Project Management* **12** (3):133-1 **36.**

Fellows, R.F., R. Newcombe, and D.A. Langford. 1985. Client control of commercial refurbishment projects. Uxbridge, Middlesex: Mechanical Engineering, Construction Study Unit, Brunel University.

Ferry, D. J., and I?. S. Brandon. 1991. *Cost planning of buildings*. 6 ed. Oxford: **BSP** Professional Books.

Hamilton, I. (1987). Development of expert systems for managerial applications. *Building cost modelling and computers*. I?. S. Brandon. London, Spon.

Heath, B. C. and M. J. Berry (1996). *An examination of the issues arising on the site from the use of standard and non-standard procurement methods and the implications of the same for project success.* Procurement system symposium CIB W92, Durban, The department of Property Development and Construction Economics, University of Natal, Durban.

Hughes, W. P., and D. Greenwood. 1996. The standardisation of contracts for construction. *International Construction Law Review, The* **13 (2).**

Jones, S. R. 1994. How constructive is construction law? *Construction Law Journal* 10:28-39.

May, A., Hon. Sir, A. Williamson, and J. Uff. 1995. *Keating* on *Building* Contracts. 6th ed. London: Sweet & Maxwell.

Love, E. D. P. and M. Skitmore (1996). *Construction project delivery system: An analysis of selection criteria weighting.* Procurement system symposium CIB W92, Durban, The department of Property Development and Construction Economics, University of Natal, Durban.

National Economic Development Office(NEDO). (1985). Thinking about building, Building **EDC, HMSO.**

Prof. Hibberd, P. and A. Basden (1996). *The relationship between procurement* **and** *contractual arrangements.* Procurement system symposium CIB W92, Durban, The department of Property Development and Construction Economics, university of Natal, Durban.

Robinson, N.M. 1990. *Contractual terms for property maintenance and refurbishment projects: Their development, selection and integration.* Paper read at CIB-70 Building Maintenance Worldwide.

Skitmore, R. M. and D. E. Marsden (1988). *"Which procurement system? Towards* **a** *universal procurement selection technique."* Construction Management and Economics(b): 71-89

Van Deventer, R. 1993. *The Law of Construction Contracts.* Chichester: Chancery Law Publishing Ltd.

Veljanovski, C. G. 1982. ***The*** *New Law-and-Economics:* ***A*** *Research Review.* Oxford: Centre for Socio-Legal Studies.

Wallace, I. N. D. 1995. *Hudson's Building and Engineering Contracts.* 1 1th ed. 2 vols. London: Sweet & Maxwell.

Wong, KC. and T.P. Albert 1995. ***A*** *fuzzy expert system for contract decision* ***making.*** Construction Management and Economics (13) 95403

Aligning Procurement Methods Toward Innovative Solutions to Environmental and Economic Needs

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Abstract
The strengths and weaknesses of complex variations of Design-Bid-Build, Design-Build, Design-Build-Operate, and Build-Operate-Transfer processes are being explored at the project level. The resulting literature confirms that knowledge, experience, and judgment are required for success, and that choice of project delivery method affects the timing, nature, and scope of innovation in technology, design, construction, operation, and finance. The growing acceptance that there is more than one project delivery option for many public infrastructure projects necessarily implies new opportunities to package projects in order to optimize not just one, but a portfolio of infrastructure facilities. Procurement systems will offer sustainable management of society's infrastructure portfolio if the lessons learned at the project level are assimilated into simultaneous planning for the delivery of collections of projects. The basic variables will be (1) choice of project delivery method and (2) choice of project financing vehicle. A four quadrant framework for analyzing and comparing project delivery and finance methods is presented, along with a summary of the fundamental elements of a long term, public/private strategy for delivering, maintaining, and refreshing the infrastructure portfolio. A three quadrant model is described to implement this strategy. The objective function will be that combination of viable projects which meets the greatest number of environmental and economic needs within multiple capital rationing restraints. Discounted life-cyclecash flow analyses (DLCCF) will emerge as the common denominator that allows these variables to be mixed, matched, and evaluated in alternative portfolios. The benefits of open, transparent, competitive procurement strategies to government, the private sector, and the public are presented and described. Establishing a stable, flexible procurement system for improving the infrastructure base is a key prerequisite to addressing broader questions related to the economy and the environment.
Key Words: Build-Operate-Transfer, Design-Bid-Build, Design-Build, Design-Build-Operate, Discounted Life Cycle Cash Flow, Project Delivery and Finance, Project Portfolios, Public Infrastructure

1. Introduction

Ostensibly new, the problems facing today's generation of governments and infrastructure planners are, in reality, quite old. These problems include: (a) getting infrastructure development started or reinvigorated to improve economic efficiency and raise the standard of living; (b) starting and sustaining private sector entities such as architectural and engineering consulting firms, construction companies, design-builders, manufacturers of supplies and equipment, and developers of new technology; (c) building public sector institutions which facilitate economic activity, encourage competition, and increase the transparency of government regulation and legislation; (d) producing steady technological refreshment of infrastructure, including replacing "dumb" with "'smart", "dirty" with "green" systems; and (e) attracting both public and private sector investment of capital. Governments continue to search for stable procurement systems which let new ideas, new technologies, new capital, and new firms in, while allowing existing firms to grow and evolve. In the US, for example, this search is as old as the nation. (1)

2. The rebirth of project delivery and finance as variables

The biggest news in the world of public infrastructure procurement is the rebirth of project delivery and finance as variables in infrastructure planning. Over the last decade, the Engineering Procurement Construction (EPC) sector throughout the world has developed broad expertise in the full range of project delivery and finance methods -- including design-bid-build (DBB), design-build (DB), design-build-operate (DBO), and build-operate-transfer (BOT). The literature confirms that, for each available delivery method, substantial knowledge, experience, and judgment are required for success. After any one of these delivery methods is chosen, successful implementation of that method requires careful planning, detailed scheduling, timely materials and equipment acquisition, and proper integration of all the design and construction elements.

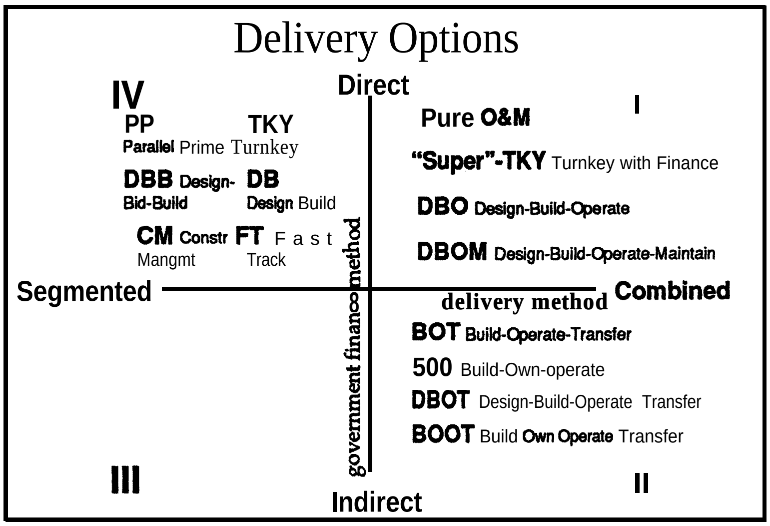
The growing acceptance that there is more than one project delivery option for most projects is directly correlated to the growing recognition that choice of project delivery method profoundly affects the timing and scope of innovation at each step in the infrastructure delivery process. Choice of delivery method directly affects choice of technology, design approach, construction methods, facility operations, and project finance. The emerging mix of project delivery and finance options necessarily implies new opportunities to package projects in order to optimize not just one, but a portfolio of infrastructure facilities. This paper explores the key elements of procurement in this new environment, and offers an integrated strategy intended to align infrastructure procurement strategy with both long term economic activity and appropriate stewardship of the environment.

2.1. Definitions

The term "infrastructure" is used in a broad sense to mean, collectively, (a) the transportation of people, goods, and information; (b) the provision of public services and utilities such as water; power; removal, minimization, and control of waste; and (c) environmental restoration. The term "project(s)" is used to refer generically to contracts awarded by public owners for the provision of capital works and/or infrastructure services.

Using metrics previously described by the author, (l-3) the Operational Framework represented by horizontal and vertical axes in Figure 1 was developed to describe the practical choices facing the public infrastructure sector at both the project and portfolio levels. The horizontal axis represents the continuum of delivery methods measured by the degree to which typical elements are segmented or combined with one another, while the vertical axis represents the continuum of financing methods measured by the degree to which government assumes the financial obligation for producing, operating, and maintaining the project throughout its life cycle. Superimposed on the framework in Figure 1 are the project delivery methods in common use throughout the world. Most of these methods are described by Gordon (4). Several variations of Design-Build-Operate and Build-Operate-Transfer are also included.

Figure 1



All the procurement methods shown in Figure 1 are defined in two dimensions: the means of project delivery and the means of project finance. The term OWNER refers to the public entity procuring infrastructure facilities or services, and CONTRACTOR refers to the successful bidder or proposer that emerges as the winner of the procurement process. DESIGN-BID-BUILD (DBB) is defined to mean a segmented delivery strategy in which design is fully separated from construction. Both are in turn fully separated from maintenance and operation of the facility once the project is turned over by the CONTRACTOR to the OWNER. In the DBB model, planning and financing of the project are also separately provided by the OWNER. DESIGN-BUILD (DB) is defined as a delivery strategy in which the-government procures both design and construction from a single CONTRACTOR. Initial planning, functional design, financing, maintenance, and operation of the facility remain as separate, segmented elements of the project, provided by the OWNER. DESIGN-BUILD-OPERATE (DBO) is defined as a delivery method in which design, construction, maintenance, and operation of the project are procured by the OWNER from a single CONTRACTOR. Initial planning and functional design are provided by the OWNER. As used in Figure 1, the DBO procurement method is defined to require that the public OWNER directly provide sufficient financing for the CONTRACTOR to perform all of the tasks assigned by the OWNER. This financing is typically provided in one of two ways (and sometimes as a combination of the two): direct cash payments by the OWNER, or delivery by the OWNER of the equivalent of direct cash payments to the CONTRACTOR, such as the right to collect user charges. BUILD-OPERATE-TRANSFER (BOT) is defined as a delivery method in which the OWNER procures design, construction, financing, maintenance, and operation of the facility as an integrated whole from a single CONTRACTOR. Only initial planning and functional design are provided by the OWNER. As defined here, the BOT method puts the risk that project receipts will not be sufficient to cover project costs and debt service squarely on the CONTRACTOR.

In actual procurements, owners present competing contractors with opportunities that vary slightly from these definitions. Such variations include: mixtures of direct cash payments and cash substitutes from the owner; the extent of initial planning or design; the length and extent of maintenance and operations obligations.

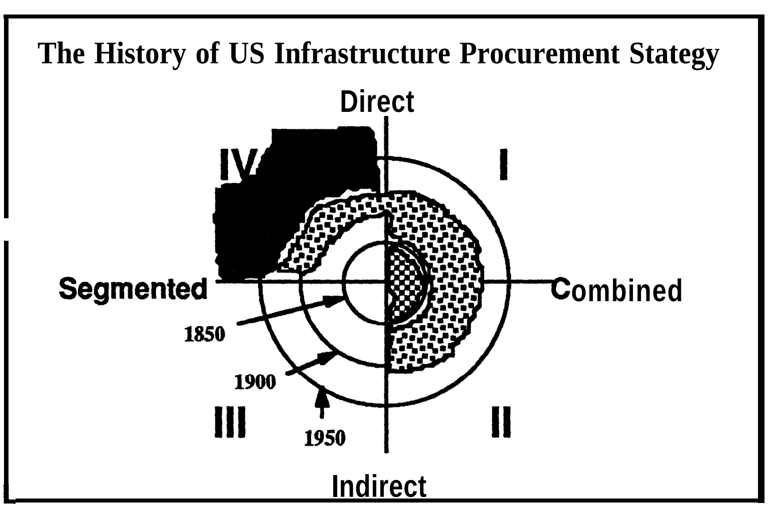
2.2. "Public or Private" - the empty, useless debate

Over the last ten years, many developed nations and international institutions that provide funding to developing nations have debated the relative merits of public and private provision of infrastructure facilities and services. Supposedly "deep" philosophic arguments over the "proper" role of government in infrastructure assumes that one such role can be identified - an assumption fundamentally at odds with the growing use of alternative project delivery methods. The debate is both hollow and futile. It is hollow because much of the world's infrastructure stock is already privately held, a trend that will likely accelerate, as the next major wave of infrastructure improvements -- information technology (IT) -- continues to be developed primarily in the private sector. It is also hollow because much of the "stuff' of publicly held infrastructure -- aircraft, railroad cars, ships, traffic controls, highways -- is not manufactured or installed by government at all, but by private companies procured by government. The public/private debate is futile because public funding levels across nearly all nations seem to be inadequate to meet government's appetite for world-class infrastructure to push national economies into the global economy.

Neither a purely public nor a purely private approach to infrastructure provision has proven to be sustainable in either the developed or developing world, particularly where financial and environmental resources are limited, and where innovations in the technology and methods associated with infrastructure continues to occur unpredictably throughout the world.

The US experience is a class example of one nation's two hundred years' experiment with various mixtures of public and private procurement strategies for infrastructure. Figure 2 presents how America has experimented with project delivery and finance methods, using the framework presented in Figure 1, modified by the addition of concentric circles representing the passage of time. Figure 2 summarizes over 800 statutes enacted by Congress prior to 1933 which led to projects, and several thousand projects funded through federal grants after World War II. (l-3)

Figure 2



America's current exclusive reliance on Quadrant IV for federal construction of public infrastructure has, since 1980, proven to be unstable because of chronic shortfalls in federal direct funding for infrastructure. The American experience is common to many of the world's nations, both developed and developing - with variations in timing and sequence. The "private v. public" tug of war for the heart and soul of infrastructure development continues in the US today, as competing ideologies argue for totally public infrastructure in Quadrant IV and totally private infrastructure in Quadrant II.

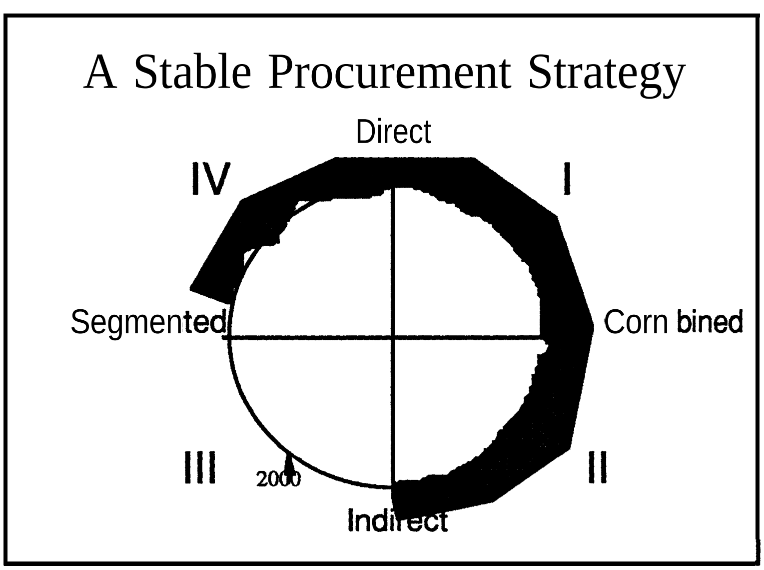
This polarizing debate now threatens to paralyze what would otherwise be an inexorable process of infrastructure renewal -- led by innovation in technology and methods, and pursued by entrepreneurs and investors. The danger is that both government and private industry will continue to see procurement strategy as an ideological choice between public and private rather than a steadily evolving mixture of both. technologies from around the world. The basic problem is how to produce and sustain a competitive infrastructure base without concentrating too much power in either the state or in the private sector, and at the same time maintaining incentives for individuals to innovate, to produce, and to improve both themselves and the infrastructure portfolio.

3. The underlying logic of procurement must change

Irregular, and often unpredictable shifts in government policy between purely public and purely private infrastructure send exactly the wrong message to designers, constructors , operators, investors, inventors, and individuals interested in making their contribution to the economy through public infrastructure. Such shifts merely confirm to decision-makers in the private sector that infrastructure is not a reliable market, and that more stable opportunities should be pursued elsewhere.

Our procurement strategy should recognize explicitly what generations of experience has already taught: innovations enter the infrastructure portfolio through each of the individual segments in the procurement process (design, construction, finance, operations, maintenance) and through combinations of these segments (DB, DBO, BOT). Only a broad mix of procurement strategies offers a stable base for broader economic and environmental strategies. Figure 3 describes this strategy graphically. No single quadrant strategy (Quadrant-IV or Quadrant II) is stable in the long term.

Figure 3



4. Fundamental elements of a sustainable procurement strategy

The fundamental elements of a procurement strategy incorporating the notion that project delivery and finance are key variables to be managed in the refreshment of the infrastructure portfolio have been previously described. (5) These elements are listed below in summary form for discussion and debate.

- A Three Quadrant Strategy in which a steadily evolving mix of public and private delivery/finance is the express goal
- Consideration of alternative project delivery and finance mechanisms as one means for verifying project viability, introducing new technology, and generating competition over quality, initial cost, and life cycle cost.
- Comparative discountedcash flow analyses of life cycle cost, in order to permit one to one comparison among the DB, DBB, DBO, and BOT contract awards.
- Project Scope, clearly defined in advance by the government, either through performance specifications, or design specifications.
- Competition in the award of projects, through well-advertised, well-marketed Requests for Proposals and Invitations to Bidders.
- Fair Treatment of Actual Competitors, through even-handed implementation of procurement processes.
- Transparency - Signaling Fairness to Potential Competitors through early statement of project and proposal requirements, and evaluation criteria.
- An Independent Engineering Check of the Efficacy of Design, to ensure public safety whenever the design function is combined with the construction function.
- Competition which is Open to Technological Change, through increased reliance on performance specifications.
- A portfolio approach to optimization, using discounted cash flow analyses over the project life cycle as the common denominator to compare alternative configurations of project delivery and finance for a collection of projects. (6)
- Continuous integration of these concepts into government procurement strategy.

5. Impacts on the economy, the EPC sector, and the environment

A three quadrant procurement strategy offers numerous opportunities for continuous evaluation of new technologies, techniques, and methods to improve the quality, cost, and environmental performance of infrastructure services and facilities. These opportunities naturally arise once the cost of current facilities and services become transparent to operators, users, taxpayers, and potential competitors, since the three quadrant strategy allows and encourages competitive pressures to replace “dirty” with “clean”, “dumb” with “smart”, and to steadily move the infrastructure portfolio toward better, faster, cleaner, and cheaper. The potential impacts on the economy, on the Engineering-Procurement-Construction (EPC) sector, and on the environment are significant.

5.1.1. The impact on innovation.

The three quadrant model permits innovations in technology to enter the infrastructure portfolio through any one of the delivery methods. The ownership, use, and rewards for innovative software can be more attractive to software developers where DBO or BOT is used, encouraging more rapid deployment of IT into control systems which integrate the functions of building, plants, and transportation systems. Improved energy conservation is a likely direct benefit.

With respect to innovation in architectural and engineering methods, the three quadrant strategy permits and encourages technology transfer of methods first employed in one quadrant to subsequent projects in other quadrants. A classic example of just such a transfer is the single gasket immersed tube tunnel design first employed on BOT projects on the cross harbor tunnels in Hong Kong, which has been. quickly transferred to the Boston Central Artery/Tunnel project, which employed-DBB as the delivery method. Innovations in construction methods are similarly transferable across the quadrants.

5.1.2. The impact on firms.

The three quadrant model encourages individuals to create and operate firms across the entire spectrum of activities associated with infrastructure development, including professional design, construction, design-build, supply, technology, operations, maintenance, finance, and combinations of these functions in broader organizations to perform DBO and BOT services. A stable, long term commitment by government to all three of the quadrants permits and encourages new entrants, and permits well established firms to compete for new opportunities in more complex markets that integrate design, construction and technology. The three quadrant model encourages firms to differentiate, to evolve, and to focus on infrastructure as an attractive market. (7, 8)

5.1.3. The impact on individuals.

The three quadrant model encourages individuals to contribute to infrastructure improvement in both new and traditional ways. Numerous points of entry and advancement are maintained through continued reliance on DBB and DB as bedrock delivery methods. Associated with these methods are traditional incentives for professional design education, practice, and licensure, as well as solid monetary incentives for the education, training, and apprenticeship of skilled craftsmen. The three quadrant model encourages entirely new groups of individuals to more actively participate in infrastructure renewal -- technology suppliers and financiers -- through the integrated procurement processes of DBO and BOT. In many of these procurements, technology, software, and finance will represent more important drivers in these competitions than engineering or construction elements.

5.1.4. The impact on competition.

The three quadrant model encourages stronger competition among firms, not only on initial cost for DBB and DB, but also on life cycle cost, time of performance, and quality of performance.

5.1.5. The impact on capital availability.

The three quadrant model encourages government to obtain independent checks of the economic and technical viability of large projects through DBO and BOT competitions. Such checks will gradually permit governments to adjust the allocation of projects across the quadrants so that private capital is reasonably and reliably attracted to viable projects in Quadrant II, and to those projects in Quadrant I where government financial backing (through cash substitutes) is clear. Private capital financing of such projects will, in turn, create new opportunities for government to better allocate direct cash payments to projects in Quadrants IV and I.

5.1.6. The impact on portfolio planning.

The three quadrant model makes scenario analysis possible, by expressly incorporating project delivery and finance alternatives into the planning process for a collection of projects, before procurement commences for individual projects. An early software appli that applies these principles to a portfolio has been developed at MIT, called CHOICES. (6) The purpose of the software is to permit alternative configurations of project delivery and finance to be explored by government planners before choice of delivery method is made.

5.1.7. The impact on government procurement institutions.

The three quadrant model necessarily implies a smaller, yet a more robust role for government in the planning, delivery, and operation of the infrastructure portfolio. Greater transparency is a substantial element of the model, including visible, reliable commitments by legislatures and regulators to: (a) a mixed delivery approach, (b) open technologies, (c) accurate statements of current costs and levels of performance, among other factors. In the three quadrant model, government has a special obligation to identify the public's functional infrastructure needs, to analyze the procurement options, to select among delivery methods, to conduct the competitions, and to monitor the results achieved, all as a prelude to repeating the entire process as technologies, skills, and needs evolve with time. Benchmarking against similar facilities and similar services provided by other governments can help to keep this process healthy and strong. Steady, sustainable improvement in the portfolio is the strategic goal.

6. Conclusion

The growing acceptance of multiple project delivery and finance methods necessarily implies that governments will be increasingly faced with strategic choices whether to use "public" or "private" mechanisms in the provision of infrastructure facilities and services. History teaches that purely public and purely private delivery mechanisms are unreliable, unstable, and averse to innovation. Steady, sustainable improvement in the infrastructure portfolio will be achieved through a transparent, -mixed strategy -- a three quadrant model -- which encourages individuals and firms to innovate, encourages technology developers and investors to enter, and which is simple for participants to understand and use. A flexible, reliable, mixed public/private procurement strategy is required if broader questions related to the economy and the environment are to be coherently addressed through procurement systems.

7. References

1. Miller JB. Toward a New American Infrastructure Development Policy for the 21st Century. *Infrastructure* 1996;Vol. 1, No.3:1.
2. Miller JB. Aligning Infrastructure Development Strategy to Meet Current Public Needs [Doctoral Thesis]. Cambridge: Massachusetts Institute of Technology, 1995. 283 p.
3. Miller JB. Engineering Systems Integration for Civil Infrastructure Projects. *Journal of Management in Engineering*, ASCE 1997;13(No. 5 Sep/Oct).
4. Gordon CM. Choosing Appropriate Construction Contracting Method. *Construction Engineering and Management* 1994;120, No. 1(MAR. 1994):196 - 210.
5. Miller JB. The Fundamental Elements of Sustainable Procurement Strategies for Public Infrastructure. *First International Conference on Construction Industry Development.* Singapore: National University of Singapore, 1997.
6. Miller JB, Evje RH. Life Cycle Discounted Project Cash Flows: The Common Denominator in Procurement Strategy. *First International Conference on Construction Industry Development.* Singapore: National University of Singapore, 1997.
7. Porter *ME. Competitive Strategy:* Techniques for Analyzing Industries and Competitors. New York: The Free Press, A Division of Macmillan, Inc., 1980.
8. Porter ME. *Competitive Advantage*: Creating and Sustaining Superior Performance. New York, New York: The Free Press, A Division of Macmillan, Inc., 1985.

DESIGN AND MANAGEMENT PRACTICE FOR A SAFE WORKING ENVIRONMENT

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Abstract
Regulations for construction design and management for health and safety are examined in relation to clients, planning supervisors, designers, principal contractors and contractors. The paper is based on interviews with construction practitioners from small and medium organisations. Research findings are reported on issues of competence and the allocation of resources together with the preparation of construction phase health and safety plans. The competence of subcontractors has to be assessed and the need for their cooperation is noted. The responsibility for the implementation of the Regulations is included together with the recognition of training needs and the use of external consultants. The instilling of a safety culture is suggested as vital to the development of a health and safety system within organisations. The relationship between duty holders is noted and the cost of implementing the Regulations illustrated from a case study. A final conclusion is made that progress on implementation is slow on the part of clients and designers. Also that a greater focus is required on the awareness of risk to the health and safety of site operatives.
Keywords: Construction, design, health, management, regulations, safety.

1 Introduction

Health and safety requirements for a safe working environment are reviewed in relation to the implementation of The Construction (Design and Management) Regulations for the UK. Problems in meeting the requirements in terms of resources, responsibilities and management systems are reported. The methodology of the investigation was based on in depth interviews with construction practitioners (20) from small and medium sized enterprises and a detailed company case study.

2 Accidents and their costs

Construction work covers many activities, techniques, materials and hazards and it is this diversity that increases the probability of accidents occurring. There is a commonality of accidents within the industry and the factors that can contribute indirectly to an accident. An accident may be defined as any unplanned event that resulted in injury to ill health of people, or damage or loss to property, plant, materials or the environment [1]. A recurring theme is that people are killed during simple, routine work and in many cases a clear lack of planning contributed to the tragedy. An underlying belief is that the majority of accidents are not caused by careless workers but by failures in control which ultimately is the responsibility of management.

3 The Construction Design and Management Regulations

The Construction (Design and Management) Regulations 1994 came int effect on the 31st March 1995 and implements EC Council Directive 92/57/EEC which relates to the provision of minimum health and safety requirements at temporary or mobile construction sites. The regulations are considered to be more demanding than the minimum requirements of the directive.

The fundamental principles on which the CDM Regulations are based are as follows:

1. Safety is to be considered systematically, stage by stage, from the outset of the project.
2. All members who contribute to the health and safety on a project are to be included.
3. Proper planning and coordination must be undertaken from the outset of the project.
4. Provision of health and safety is to be within the control of competent persons.
5. Communication and the sharing of information between all parties must be included.
6. A formal record of safety information for future use must be made.

The CDM Regulations bring health and safety management, on an obligatory basis, into the planning and design of construction work. Thus the contractor is no longer left with the sole responsibility of health and safety during construction.

3.1 Clients

The philosophy of improving health and safety management by way of the regulations starts with an obligation to establish a team that will have the competence and resources to manage the project without any undue risk to health and safety. The appointment of a planning supervisor is central to a clients responsibilities. The planning supervisor should be appointed as early as possible to allow adequate time to address issues during the planning and design stage, including the preparation of the pretender stage health and safety plan. Any information in the clients possession should be made available to the planning supervisor.

3 .2 Planning supervisors

The post of planning supervisor is a new statutory requirement, which imposes duties but gives no powers. This appointment made by the client has the role of coordinating the design and planning from a health and safety viewpoint, with the aim of ensuring that risks identified in the construction of the project including those associated with maintenance or demolition are eliminated or minimised. The role involves the preparation of the pretender stage health and **safety** plan which is passed to principal contractors and the principal contractor will have the task of developing the plan. The client is entitled to advice from the planning supervisor, on the competency and adequacy of the health and safety resources available to designers and the principal contractor, prior to their appointment.

3 .3 Designers

Designers may include architects, consulting engineers, surveyors, specifiers, principal contractors and specialist subcontractors. The term “design” has a wide definition under the regulations and includes drawings, details, and specifications. The main requirement of designers is to deal with health and safety issues by designing them out “so **far** as is reasonably practicable”, that is by balancing the risk against the cost of averting it. A judgement has to be made so that the cost is counted not just in financial terms but also in relation to fitness of purpose, aesthetics, buildability or environmental impact.

The responsibility placed on the designer is to consider if the hazard can be prevented from arising so that the risk can be avoided. If this cannot be achieved measurements have to be taken to minimise and control the risk. The achievement of this will involve consideration not only of the construction but also how the completed project is to be maintained, repaired and demolished, together with those people involved in or affected by these activities. When there are risks that are not reasonably practical to avoid, information requires to be included with the design to alert others to the risks that they cannot reasonably be expected to know.

3 .4 Principal contractors

A client who intends to appoint a principal contractor has to be satisfied that the contractor has the competence to carry out or manage the construction work and has adequate resources to comply with the requirements imposed under the statutory provisions. Once the principal contractor is appointed they will develop the pretender health and safety plan into a working project document, ensuring that it has all the necessary information for securing the health and safety of all those carrying out construction work and those who may be affected by it.

All information relating to the project may not be available to fully develop the health and safety plan before work commences, but the general framework and key tasks during the initial stages should be included. When developing the health and safety plan, the principal contractor is required to assess the risks at each of the main stages within the construction phase. Information may be required from other contractors, including risk assessments and safety method statements, to facilitate this development. Finally, information held by the principal contractor which needs to be included in the health and safety file should be passed to the planning supervisor.

3 .5 Contractors

Contractors duties under the CDM Regulations are in support of those imposed on the principal contractor. Similarly they have responsibility for the health and safety of their own employees and others effected by their work under the existing health and safety legislation. The key duties are to give the principal contractor information on risk assessments, on how they propose to carry out the work and what steps they will take to control and manage any risks. This will require cooperation with the principal contractor and compliance with any directions given by them.

3.6 The Health and Safety Plan

The health and safety plan is a mechanism to improve the communication of matters affecting health and safety. The content and detail of the plan will be dictated by the size and complexity of the proposed project. During the pretender stage, the plan is prepared on information obtained from the client and designers and where appropriate the planning supervisor. The content of the plan, in addition to being relevant, should contain an indication of where principal risks occur in the design and the precautionary measures to be taken during construction. If there is a significant resource implication in dealing with an identified risk, tenderers will be required to respond on how this will be implemented.

3.7 The Health and Safety File

On completion of the project the planning supervisor is required to ensure that a health and safety file is prepared and handed over to the client. During the currency of the project those who carry out design work will need to ensure, so far as is reasonably practical, that information about any feature of the structure, which will involve significant risks during the structures lifetime, are passed either to the planning supervisor or to the principal contractor. The principal contractor may also require to obtain details of services, plant and equipment from specialist suppliers and installers.

4 Competence and allocation of adequate resources

The initial task for a principal contractor is to demonstrate competence to a prospective client. The standard means of adjudicating competence is by assessing responses to a pre-tender questionnaire. The validity of this method in isolation may be suspect and responses received do not necessarily reflect the true structure and strategy of a company with regard to health and safety. Planning supervisors whenever possible preferred to confirm the responses received by visiting principal contractors to carry out an informal interview. Pre-tender questionnaires are being given where the level of detail is disproportionate to the scale and complexity of the project. This has resulted, on several occasions, in smaller sized contractors declining to tender for work.

5 Preparation of construction phase health and safety plans

The findings indicate that initially principal contractors had encountered difficulty in preparing construction phase health and safety plans. The reasoning for a contrast in content and quality of the plans may be that the industry has not yet adopted a common format, although responses are found to be broadly based on the guidelines given by the Health and Safety Executive. Similarly there is no common format for the preparation of risk assessments, the majority having a format based on generic risk assessments provided by safety advisers. Evidence from planning supervisors is that the CDM Regulations have focused principal contractors on their duties under the Management of Health and Safety at Work Regulations 1992.

6 Competence of, and co-operation with, other contractors.

Only three of the companies interviewed have adopted a comprehensive procedure for assessing the competence of sub-contractors. Two of these had an accredited quality assurance system which encompassed the competence and monitoring of sub-contractors. The other companies relied primarily on the previous track record of the sub-contractor for assessment. Principal contractors are requesting health and safety related information from their sub-contractors but they are not ensuring that these contractors provided training and information for their employees. Co-operation is a requirement with all contractors, however once the sub-contract order is placed there is little to indicate any formal means of co-operation.

7 Responsibility for implementation of the Regulations

In all except two of the companies studied responsibility for preparation of health and safety plans and implementation of duties under the Regulations are the role of one senior manager. No one has employed extra personnel to assist with implementation and responsibility has fallen as an additional burden on the manager responsible for safety with in the company. The assessment of cost and time in preparing and updating the plan as carried out in a detailed case study indicates that the task takes up a significant proportion of a managers time.

8 Recognising training needs

The study has indicated a high awareness of the CDM Regulations amongst management in all companies. All companies, with the exception of the smallest sized company, have sent personnel on CDM related courses. The positive attitude taken by the companies studied in relation to management training is not mirrored in respect to operative training. Two of the companies have sent a small number of craftsmen on safety awareness courses as part of the requirement of a Construction Skills Certification Scheme. Membership of construction training groups is seen as a cost effective means by which companies can train and increase awareness amongst their operatives and a high proportion of companies interviewed were members of such a group.

9 Use of external consultants

A means by which small to medium sized principal contractors can display their competence to the client is by employing an external consultant or by being a member of a safety group. The services of a safety consultant who visits sites and reports on findings is deemed to be active monitoring and goes some way towards satisfying the monitoring requirements under the Regulations. External consultants can also advise on safety management systems and safety policies. A possible disadvantage of this approach is that documentation does not always directly relate to the specific company.

10 Instilling a safety culture

The owner managed companies studied have developed strong cultures despite the often cynical nature of the industry. The strength of safety culture is not as clear and success depends on how strong the owners exert a positive influence in relation to health and safety. Levit [2] has written that a leader who believes in safety gives direct evidence of this by holding all managers accountable for safety of their subordinates and by being willing to commit real and substantial organisational resources to training and monitoring safety related activities. In doing so the owners have to establish safety accountability within the organisation, train site managers in safety supervisory techniques, train site operatives in safe working practices, and require detailed preplanning of work.

11 Development of a health and safety management system

The development of a formal health and safety management system is seen to be essential for the control of risk. Within a company the pooling of knowledge and experience is a key aspect of risk control. Participation complements control in that it encourages the ownership of health and safety systems by employees at all levels. Participation also establishes an understanding that the organisation as a whole and those working in it benefit from a good health and safety performance.

A comprehensive system is made up of a variety of formal and informal means of communication by which there is an adequate flow of information throughout the organisation. However there is no clear indication that an integrated system had been adopted within the culture of the companies surveyed. The two companies with quality assurance systems have an advantage in that quality and safety were considered to be related. The Health and Safety Executive (HSE) [3] in its guide to successful health and safety management comment that organisations who have adopted a total quality management philosophy achieve particularly high standards of health and safety performance.

12 Relationship with other duty holders

The case study gave clear evidence that clients were, during the introductory period of the legislation, passing the planning supervisor duties on to the principal contractor. There is evidence of a lack of awareness on the part of the clients and a refusal to appoint a planning supervisor [4]. The research indicates that designers were initially slow to respond to the need for design risk assessments. There is also little evidence to show that buildability, a contributing factor to some accidents, is being considered.

The duties of a planning supervisor are as varied as the projects on which they are being asked to advise. The required core of competence is still being developed at the moment in what is becoming a new area of consultancy. The HSE recognises this and recommendations have been produced with suggestions for the training of those contributing to the design and planning supervision function [5].

13 Cost of implementing the Regulations

In the consultative document for the Regulations the Health and Safety Commission (HSC) estimated that the total cost to the construction industry in implementing the Regulations would be in the region of £550 million, based on an industry output of £37 000 million for 1991 [6]. The HSC estimated that compliance by designers for their new duties might cost an additional £290 million each year and the additional cost to planning supervisors and principal contractors an additional £185 million each year. The percentage of industry output costs for planning supervisors and principal contractors were therefore estimated to be 0.5% of the value of industry output. This figure is comparable with the case study where the cost of compliance was calculated to be 0.45% of the companies turnover.

14 Conclusion

The CDM Regulations are aimed at improving the overall management and coordination of health and safety throughout all stages of a construction project with the aim of reducing the number of serious and fatal accidents and causes of ill health that occur in the industry. The principle contractors interviewed have shown an awareness of their duties and introduction of the regulations has acted as a stimulus to demonstrate compliance in relation to health and safety. Risk assessments are now having to be prepared by contractors but there is evidence of disparity in their format and content.

Compliance with the CDM Regulations is a learning curve for all the duty holders and even for the enforcers. Pretender safety plans have assisted in focusing attention on prevention or control of risks prior to commencement of work on site. Difficulty has been encountered by small to medium sized principal contractors in the preparation of construction phase health and safety plans. However, planning supervisors have generally adopted a policy of working with principal contractors and assisting them in developing a format for the plan which will satisfy the requirements of the Regulations.

Input is required to communicate the CDM message to site operatives and subcontractors and the research has indicated that there is a need for the managers of principal contractors to instil a safety culture within their organisations from the top down. Health and safety management is a combination of practical knowledge, experience, knowledge of the law assessment of risk and effective control. The operation of an effective health and safety management system will facilitate traceability within a company should the HSE undertake an investigation.

The regulations were introduced with the intention of creating an integrated approach to health and safety through the increased involvement clients and designers. Some two years after the implementation of the regulations some duty holders are still addressing the issue of compliance. A finding of the research was that informed clients were discharging responsibility for the regulations directly on to principal contractors. Designers were not always taking a significantly different view as regards to the buildability of the structure and information on risk was not passing down to the operatives on site. If the purpose of the CDM Regulations is to reduce the number of accidents, this purpose is being clouded by practitioners unable to assess the requirements in proportion to the complexity and risks of specific projects. A review is required that moves the focus away from a paper bureaucracy towards a practical means by which principal contractors instil1 an awareness of risk to the health and safety of site operatives.

References

1. Health and Safety Executive (1983) ***Construction Health and Safety 1981-82,*** HMSO.
2. Levit, R.E. (1987) ***Construction Safety Management,*** McGraw-Hill.
3. Health and Safety Executive (1995) ***A guide to managing health and safety in construction,*** HMSO.
4. Hoare, S. (1996) ***Has CDM flopped already?*** Construction News, 11 April.
5. Natrass, S. (1996) ***CDM Regulations - Training of those contributing to the design*** and ***planning supervision function***, HSE paper 26 February.
6. Joyce, R. (1995) ***The CDM Regulations Explained***, Thomas Telford.

The role of procurement practices in occupational health and safety and the environment

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Abstract
Inadequate, or the lack of health and safety negatively effects both the construction and built environments resulting in fatalities, injuries and disease. Procurement practices encapsulate inter alia: bidding practices; contract documentation, and project leadership, which in turn influence: client involvement; co-ordination of design and construction; design, details and specification; project priorities; project duration and project relationships.

To this end the findings of various descriptive surveys will be presented which indicate, inter alia: bidding practices; client involvement; design and details; project duration; partnering and the incidence of subcontracting to influence construction and occupational health and safety, ergonomics and the environment.

The need for procurement practices which enhance the construction and built environment, health and safety, and ergonomics included, is amplified by: the total cost of accidents; the cost of redressing unsuitable or polluted environments and the synergy between occupational, health and safety, ergonomics, productivity, quality, schedule and the environment.
Keywords: Procurement practices, health and safety, environment, cost

1. Introduction

The World Commission on Environment and Development [1] defines sustainable development as "Development that meets today's needs without compromising the ability of future generations to meet theirs".

The construction industry has wide environmental impacts, originating in land use, energy and natural resources consumption, pollution and upstream industries [2]. However, often environmental concerns are interrelated with construction health and safety issues [3]. Accidents not only result in considerable pain and suffering but marginalise productivity, quality, schedule, and negatively affect the environment and consequently add to the cost of construction [4]).

Barrett & Curado (1996) maintain that in order to sustain the present levels of satisfaction of the individual's higher level needs (social, esteem and self-actualisation) humankind is required to re-address the satisfaction of physiological and safety needs, by means of environmental preservation.

2. Impact of construction

Construction by its very nature represents an ergonomics, and health and safety problem as it requires, inter alia: bending; working in awkward or cramped positions; reaching away from the body and overhead; repetitive movements; handling heavy material and equipment; use of body force; exposure to vibration and noise, and climbing and descending [5].

According to March (1992) the industry impacts on the environment at a number of levels: globally; on the community at large, and fmally on the individual (Table 1).

Impact	Process	Effect
Global	Extraction	Energy, Timber, Water
	Materials manufacture	Energy, CFCs
	Building in use	CFCs (Refrigeration etc), Energy, Sewage
	Demolition	CFCs. Burning
	Impact of planning	All those Below
Community	Extraction	Noise/Dust, Traffic, Landscape, Ecology, Water
	Impact of design	Ecology, Aesthetics
	Construction phase	Site activities (noise, dust) Waste disposal, Traffic
	Building in use and management of the built resource	Noise, Traffic, Legionella, Fumes/Dust, Sewage
	Demolition	Noise/Dust, Waste Disposal &/or Reduction
Individual	Construction operatives	Health hazards, Safety
	Building user	Sick Building Syndrome (SBS), Legionella, Allergies, Fibres, Dusts, Pesticides Gases (random/volatiles)

Table 1: The construction industry's geographical impact [6].

3. cost

The cost of accidents can be categorised as being either direct or indirect. Direct costs tend to be those associated with the treatment of the injury and any unique compensation offered to workers as a consequence of being injured and are covered by workmen's compensation insurance premiums. Indirect costs which are borne by contractors include: reduced productivity for both the returned worker(s) and the crew or workforce; clean-up costs; replacement costs; stand-by costs; cost of overtime; administrative costs; replacement worker orientation; costs resulting form delays; supervision costs; costs related to rescheduling; transportation, and wages paid while the injured is idle [7]. Various studies have realised differing ratios between the indirect and direct costs: 1,67 times for non-minor injuries and more than 5 times for minor injuries with direct costs less than US$50 [8], & 20 times [9]. Research indicates the total cost of accidents to constitute, inter alia, 6,5% of the value of completed construction [10] and approximately 8,5% of tender price [11].

4. Potential practices

The United States Civil Engineering Research Foundation (CERF) 1994 study of leading construction industry practitioners, academics and government officials worldwide analysed five distinct, but interrelated areas of practice: management and business practices; design technology and practices; construction methods and equipment; materials and systems, and public and government policy. According to Dreger [12] the study provides an excellent base of common goals and issues which can be addressed to realise significant environmental improvements in sustainable development.

4.1 Total Quality Management (TQM)

According to Levitt & Samelson [13] TQM has as its main thrust continuous improvement in customer satisfaction, employee satisfaction, productivity, and health and safety. The TQM mission in construction is to realise a quality product i.e. an error-free one for the user by preventing errors in the construction process by integrating health and safety, productivity and quality.

Dreger [12] maintains the application of its principles has the potential of realising a quality project in all respects and beneficial results to all stakeholders. Preference should be given to designers and constructors who practice TQM.

4.2 Constructability

Constructability is a system for achieving optimum integration of construction knowledge and experience in planning, engineering, procurement and site operations, and the balancing of various project and environmental constraints to achieve overall project objectives [14].

The benefits of applying constructability management on the Toyota Car Manufacturing Facility at Altona, Australia include: completion ahead of schedule; below budget; to quality and health and safety standards [14].

4.3 Client influence
Clients influence health and safety both positively and negatively, either directly or indirectly. Indirectly through: project documentation; optimising project schedule; requiring of quality management systems (QMS's), and pre-qualifying contractors on health and safety. Directly through: imposition of permit systems; conducting health and safety audits; educating and training the personnel of contractors and referring to health and safety throughout the construction process [4].

4.4 Design influence
Designers influence construction health and safety and sustainable development as a result of project concept, design and -details, specifying materials and processes, advising regarding procurement systems including project documentation and project duration and interacting with clients with respect to health and safety [15].

4.5 Procurement systems
According to Dreger [12] the form of construction delivery affects contractual relationships and the development of mutual goals. Within the context of sustainability the Design-Build contract form, which establishes one entity to provide both design and construction, has the greatest potential for success as it creates common project goals.

Generally, although references are made to health and safety in standard South African contract documentation, it is indirect, hardly coercive, and depending upon the level of commitment, contractors continue to address health and safety to varying degrees. With the exception of indirect references to the construction environment, no references are made to the environment per se. Procurement systems are such that contractors frequently find themselves in the iniquitous position, that should they make the requisite allowances for health and safety, they run the risk of losing a tender or negotiations to a less committed competitor [16].

4.5.1 Pre-qualification
The purpose of pre-qualification in the health and safety sense is to provide a standardised method for selecting contractors on the basis of demonstrated safe work records, health and safety commitment and knowledge and the ability to work in a healthy and safe manner [17].

4.5.2 Partnering
Partnering brings the various stakeholders involved in a project: client; designers; general contractor; subcontractors, and suppliers together and entails inter alia, developing mutual goals and mechanisms for solving problems, which effectively complements health and safety [13].

4.5.3 Proj ect duration
Project duration can influence health and safety as a shortened project period invariably results in an increase in the number of workers; the number of hours worked per worker, or even a combination of the two; the amount of plant and equipment, and the number of subcontractors simultaneously undertaking work per period of time. This intensification increases the possibility of incidents [16].

4.6 **Systems**

Problems related to health and safety, productivity and quality can frequently be traced to substandard, inconsistently applied or non-existent operating procedures and practices. Standard operating practices and procedures are the core component of quality management and health and safety management systems as they guarantee uniformity of operation throughout an organisation. They effectively ensure that each' time a task is performed it is done consistently, correctly and safely [18].

Ultimately the implementation of a quality management system (QMS) on a project will ensure that construction conforms to specified requirements in all respects as it identifies the procedures, checklists, resources, activities and responsibilities [16].

4.7 Legislation

The promulgation of the Construction (Design and Management) (CDM) Regulations 1994 in the United Kingdom is attributable to two aspects. First the need for a radical improvement in health and safety resulting from a cultural change and adoption of a health and safetv culture bv all stakeholders in the industry: clients; designers, and contractors, from inception through to execution. Second, the Temporary or Mobile Construction Sites Directive (TMCSD).

The contractor no longer takes sole responsibility for site health and safety as there is now a statutory link between clients and designers, site health and safety, fatalities and injury [19].

5. Research

The salient findings of a number of descriptive postal surveys conducted nationally among various survey populations in South Africa are presented.

5.1 Project Management Practitioners

47 members of the Project Management Institute (SA Chapter) responded to this survey to determine the role of project managers in contractor health and safety.

5.1.1 Productivity and quality were the aspects identified most frequently as being negatively affected by inadequate health and safety (Table 2).

Aspect	Response (%)			
	Yes	No	Don't know	Total
Cost	72,3	19,2	8,5	100,0
Environment	66,0	23,4	10,6	100,0
Productivity	87,2	10,6	2,2,	100,0
Quality	80,8	17,0	2 , 2	100,0
Schedule	57,4	29,8	12,88	100,0
Client perception	68,1	19,1	12,8	100,0

Table 2: Aspects negatively affected by inadequate health and safety

Health and safety is a prerequisite for productivity and quality as, housekeeping, inter alia, complements access and ergonomics.

Accidents result in increased cost, damage to the environment and can substantially retard progress.

Clients' requirements include not only completion on time, to quality standards, within budget, but also without fatalities and injuries which can have a negative effect not only on a client's perception of a contractor, but on the contractor's and client's image as well.

5.1.2 95,8% responded that inadequate or the lack of health and safety increased project risk. Accidents and disease result in variability of resource which in turn increases project risk.

5.1.3 66% stated that health and safety is negatively affected by competitive tendering.

5.1.4 Pre-qualification of contractors on health and safety was advocated by 68,1%. Pre-qualification will ensure that health and safety conscious contractors are engaged. A contractor's commitment to health and safety is also an indicator of their likely approach to the environment and management in general.

5.1.5 Only 5 1,1% responded that health and safety is negatively affected by short proj ect periods.

5.2 General Contractors

71 contractors who are members of the Building Industries Federation of South Africa (BIFSA) or the South African Federation of Civil Engineering Contractors (SAFCEC) responded to this survey to determine the influence of design on health and safety.

5.2.1 Table 3 tables the frequency to which aspects of design can negatively affect health and safety.

Aspect/Factor	Frequency (%)
Design	50,0
Method of fixing	47,1
Content of material	38,6
Mass of material	38,6
Size of material	37,1
Edge of material	35,7
Position of components	28,6
Surface of material	27,1
Details	17,1
Area of components	14,3

Table 3: Aspects which can negatively affect health and safety

Design and method of fixing were probably identified due to it being difficult, or impossible to circumvent problems arising therefrom, whereas the wearing of personal protective equipment can circumvent, inter alia, edge and surface of material, albeit at expense, and in cases to a degree.

5.2.2 68% stated that health and safety is negatively affected by competitive tendering.

5.2.3 Pre-qualification of contractors on health and safety was advocated by 58,6%.

5.2.4 56,3% responded that health and safety is negatively affected by short project periods.

6. Conclusions

Construction impacts on both health and safety and the environment during the construction process and in the built environment. Accidents, disease and damage to the environment contribute to the cost of construction. Health and safety complements the environment, cost, productivity, quality, schedule, the environment, and therefore customer satisfaction.

Procurement systems, practices and legislation influence health and safety and environmental practices, all stakeholders – state, clients, designers, contractors, subcontractors and suppliers playing a role.

Design-Build contracts are the preferred procurement system as common project goals result more readily from the integration of design and construction. Health and safety and sustainability of the environment are enhanced by: constructability management which affords / engenders prioritisation of health and safety and the environment; partnering which facilitiates multi-disciplinary contributions; pre-qualification which ensures committed contractors are engaged; TQM which is the strategy to facilitate continuous improvement: QMS's which assure that work is executed correctly and consistently, and safe work procedures (SWP's) which assure that work is executed in accordance with process proved steps.

7. Recommendations

Legislation should be evolved that engenders prioritisation of health and safety and the environment by all stakeholders.

Health and safety and the environment should be included as project requirements.

Procurement systems should be evaluated in terms of their influence on health and safety and the environment prior to their selection for projects.

Practices such as constructability management, partnering, and pre-qualification should be implemented on projects.

The implementation of QMS's and SWP's should be made project requirements.

8. Acknowledgements

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9. References

1. World Commission on Environment & Development (1987) *Our Common Future,* Oxford University Press, London.
2. Barrett, P.S. & Curado, M.T. (1996) Quality and environmental management: How should the construction industry face new panaceas? *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernization and Education,* Beijing, October 1996. CD – File:///D1/papers/050-059/050/p.050.htm
3. Coble, R.J. & Kibert, C.J. (1994) The environment as a construction safety concern. *Proceedings of the 5th Annual Rinker International Conference focusing on Construction Safety and* Loss *Control,* Florida, October 1994. pp. 535 – 542.
4. Smallwood, J.J. (1997) Client influence on contractor health and safety in South African construction. *Proceedings of the 1st Construction Health and Safety Conference in Construction: Current and future challenges,* Cape Town, October 1997. pp. 95 – 104.
5. Schneider, S. & Susi, P. (1994) Ergonomics and construction: A review of potential hazards in new construction. *American Industrial Hygiene Association Journal, 55* (July). pp. 635 – 649.
6. March, C.M. (1992) Construction and environment – a management matrix. *Chartered Builder,* June. pp. 11 & 12.
6. Hinze, J. (1994) Quantification of the indirect costs of injuries. *Proceedings of the 5th Annual Rinker International Conference focusing on Construction Safety and Loss Control,* Florida, October 1994. pp. 521 – 534.
8. Hinze, J. (1992) Indirect costs are a major portion of job site injury costs. *Concrete Construction,* March. p. 229.
9. Grossman, D. (1991) Construction industry builds a safe workplace. *Safety and Health,* April. pp. 48 - 51.
10. The Business Roundtable. (1982) *Improving Construction Safety Performance,* The Business Roundtable, New York.
11. Anderson, J. (1997) The problems with construction. *The Safety and Health Practitioner,* May. pp. 29 & 30.
12. Dreger, G.T. (1996) Sustainable development in construction: Management strategies for success. *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernization and Education,* Beijing, October 1996. CD – file:///D1/papers/160-169/163/p.163.htm
13. Levitt, R.E. & Samelson, N.M. *Construction Safety Management.* 2nd Edition, John Wiley & Sons Inc., New York.
14. McGeorge, D. and Palmer, A. (1997) Construction Management new directions, Blackwell Science Ltd., Oxford.
15. Smallwood, J.J. (1996) The influence of designers on occupational health and safety. *Proceedings of the 1st International Conference of CIB W99 – Implementation of Safety and Health in Construction Sites,* Lisbon, September 1996. pp. 203 – 213.

16. Smallwood, J.J. (1996) The role of project managers in occupational health and safety. *Proceedings of the 1st International Conference of CIB W99 – Implementation of Safety and Health on Construction Sites,* Lisbon, September 1996. pp. 203 – 213.
17. Brandner, L.L. (1993) Contractor safety pre-qualification process. *Proceedings of the 3rd Annual Construction Safety Conference*, Illinois.
18. Hood, S. (1994) Developing operations procedures: *9* Steps to success. *Accident Prevention,* May/June. pp. 18 – 21.
19. Jeffrey, J. & Douglas, I. (1994) Safety performance of the UK construction industry. *Proceedings of the 5th Annual Rinker International Conference focusing on Construction Safety and Loss Control,* Florida, October 1994. pp. 233 – 253.

Exploring the cultural dimensions of construction procurement - dealing with difference to achieve sustainable development

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Abstract

The cultural characteristics of individuals and organisations impact directly upon relationships between construction suppliers, clients and others with interests in the built environment. This exploratory paper seeks to flag up some of the key cultural issues and dimensions which will be significant in attempts to improve the environmental impact of buildings.

Barriers to environmental improvements are presented alongside the range of values which motivate people to bring about those improvements. The paper emphasises the importance of understanding the individual, sectoral , organisational and national differences which are likely to be encountered. It offers preliminary ideas on how they might be recognised, using the framework of cultural dimensions developed by Hofstede.

Whilst the paper considers wide ranging issues it also presents two practices; Value Management and Partnering, as existing frameworks which are beginning to yield benefits for their practitioners, both customers and suppliers. They offer a way forward for sustainable construction procurement practice.

Key **words:** Procurement, culture, change, environmental improvement

1.0 Introduction

This paper examins how different groups located on the demand and the supply sides of the UK construction industry view the environmental improvement of buildings. The differences and conflicting views which are present throughout the construction supply chain act as substantial barriers to the application and development of environmental technologies, of new ways of working, and of general progress in tackling the more difficult issue of precisely what constitutes ‘sustainable’ construction. In this paper we present:

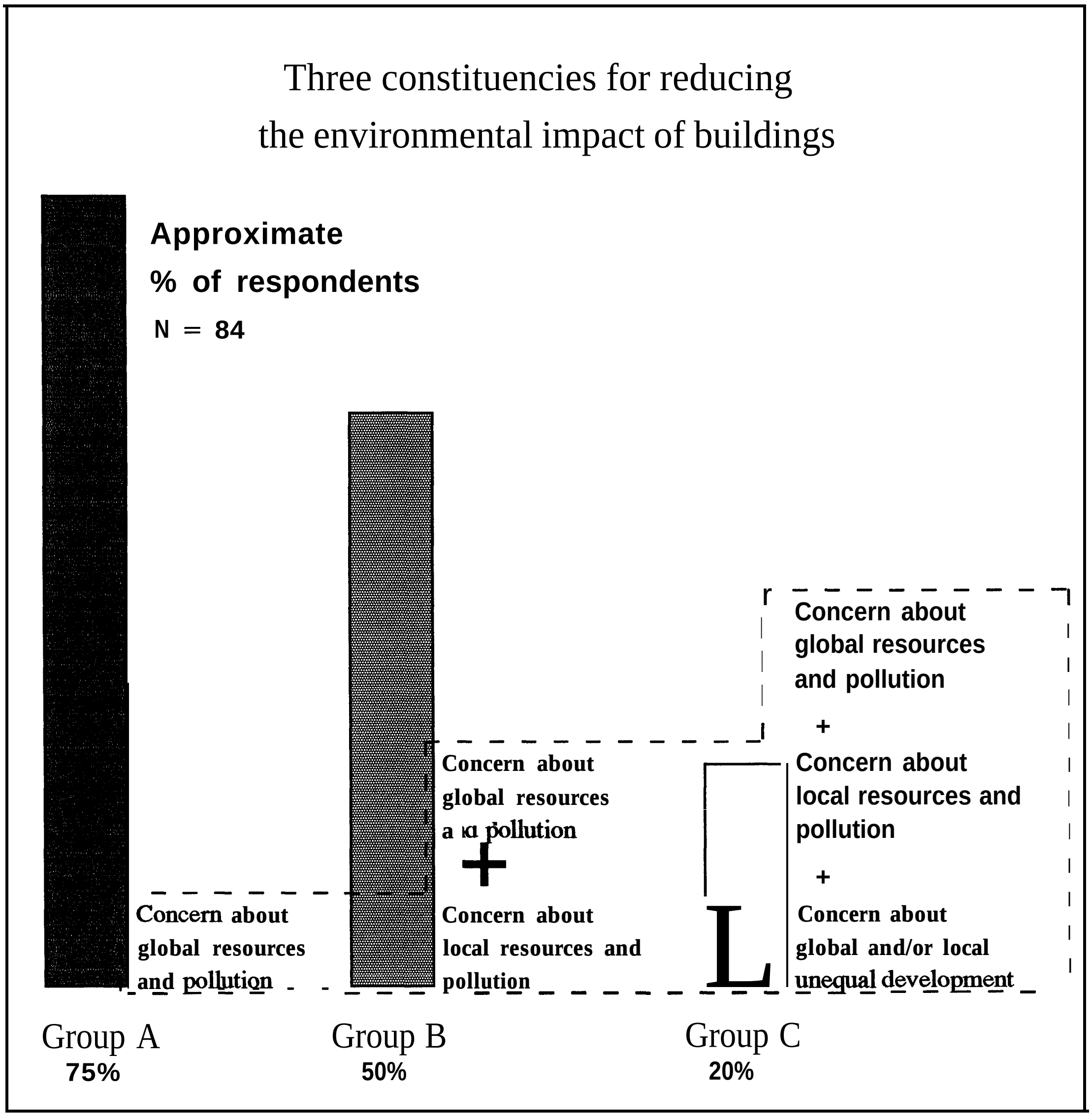
- some of the examples of difference encountered amongst those working for environmental improvement in buildings
- some of the barriers to the implementation of environmental technologies
- discussion, in the context of construction practice, the key cultural characteristics and dimensions,
- value management and partnering as new ways of working which accommodate these cultural issues

Change has been formally recognised as essential in the UK construction industry in order to bring about improvements to its productivity, efficiency, and quality and to reduce its costs. Fundamental cultural changes have been called for in The Latham Report “Constructing the team” **(1994) [1]**. Although these have not yet been achieved, new ways of working are emerging which can more easily accommodate the different (and sometimes conflicting)values of clients, designers and construction teams. ‘Value management’ and ‘partnering’ are two approaches which can yield dramatic benefits for their practitioners, both customers and suppliers alike. Like any change process, movement towards sustainability is more likely to succeed if this process is explicitly managed. This will require that more time, effort and understanding is devoted to managing the cultural components and dimensions of construction procurement.

2.0 Discovering differences amongst those involved in bringing about environmental improvements in construction

It is easy to assume that everyone involved in attempting to improve the environmental performance of buildings is working to a broadly similar agenda. The limited evidence available suggests otherwise, however. For example, Eclipse Research Consultants’ **(1996)** supply-side survey of the actions **[2]** which “leading-edge” architects and engineers in the UK said they were taking to reduce the environmental impact of new build and refurbishment work clearly identified the existence of three separable (but overlapping) agendas, see Figure **1.** This figure illustrates the percentage of respondents who said they were motivated by the three agendas described below.

Figure 1 Three overlapping agendas for reducing the environmental impact of buildings



Taken from Eclipse (1996)

1. The first agenda, Group A in Figure 1, is mainly focused on macro/global issues, of concern to global warming and ozone depletion., and, to a lesser extent, tropical rainforest destruction. Those concerned with this agenda are primarily acting to reduce the consumption of fossil fuels in buildings.
2. The second agenda, Group B in Figure 1, is wider. It also embraces these macro/global issues but adds to them more local or site- or project-specific ones (mainly to do with recycled or reusable materials and/or protecting or promoting local flora or fauna). Those focused on this broader agenda may also be concerned, for instance, with the specification of environmentally benign materials as well as the provision of nesting boxes for endangered bird species.
3. The third agenda, Group C in figure 1, is wider still. It embraces both the macro/global and local/site-specific issues of the other two and adds a third set mainly to do with public participation in decision-making and social equity. Those concerned with this broadest agenda may, for instance, be involved in self-build projects or in the use of unskilled labour drawn from the unemployed, or they may be concerned that their specifications and working practices conform to the emerging requirements of 'fair trade' and "ethical sourcing" both locally and globally.

Eclipse's survey showed that the narrowest of these agenda (Group A,) is the most frequently pursued (75% of respondents)and that the broadest (Group C,) is the least frequently encountered (20% of respondents). Clearly, there is an enormous difference here in the focus of attention, the range of issues considered and the underlying motives and aspirations of those pursuing these three agendas. These differences are rarely acknowledged yet they are substantial. Unless they are made explicit, they can be a severe stumbling block to effective collaboration, even amongst those who say they are committed to the environmental improvement of buildings.

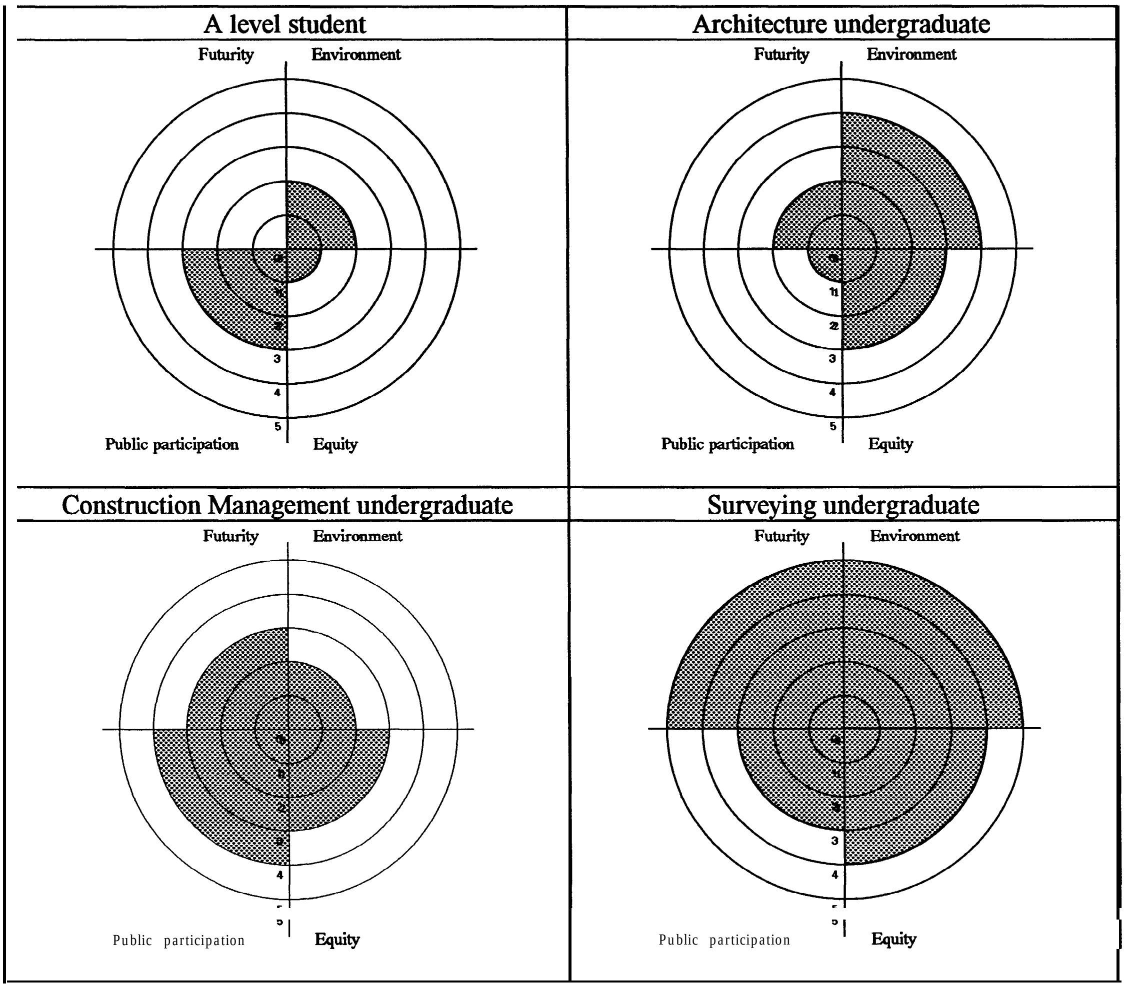
Similar differences emerge if we attempt to unpack the much more difficult notion of 'sustainable development'. As has been widely recognised by Palmer et al, 1997, this term is made up of 'fuzzy buzzwords' [3] - terms that appear to encapsulate a discrete notion but which have multiple interpretations. As a result, they are capable of appearing to unite people under what is actually a (falsely) shared umbrella. Eclipse have developed a simple, self-assessment, mapping technique [4] to allow people to gauge how committed they are to the four principles underlying sustainable development (Mitchell et al, 1995):

- futurity - concerns about future generations
- environment - concerns for integrity of eco-systems
- equity - concerns for today's poor and underprivileged
- public participation - concerns that individuals can participate in decision making

This technique has now been used widely - on the supply side with architects, engineers and building surveyors; on the demand side with client and building occupant representatives, with members of the general public, 'A' level school students and first year undergraduates in construction disciplines; as well as with a wide range of research communities involved in working on sustainable cities.

The results of using this mapping technique are revealing. We clearly cannot assume that other people share our own commitment to sustainable development, whatever that is. Some people are strongly committed to all four principles, others are uncommitted to all or some of them. Figure 2 [5], illustrates typical responses from a range of undergraduate professionals. Typically, whatever their background (age, sex,

Figure 2 Individual students' stated commitment to the principles of sustainable development



Taken from Cooper (1997)

Cooper, I., 1997, Designing on the Future: High Tech Sustainability?, Building Sights: Visions for the future of construction, Visions for the Future Report 6, Proceedings of a workshop organised by the British Association for the Advancement of Science on behalf of Technology Foresight and EPSRC, Salford University, 5-6 December, 1996, British Association for the Advancement of Science, pp. 4-7.

or occupation), undergraduates in the UK and from elsewhere in Europe are fairly strongly committed to one or more of the principles. On average (but not universally), they are most committed to 'futurity' and ‘environment’, less so to ‘public participation’, and least to ‘equity’.

The surveys have shown that, perhaps counter-intuitively, older people tend to be more committed to the principles than younger ones. And as much divergence in commitment can be found within the responses from particular age or occupational groups as there is between them. No one group has a monopoly on commitment; or is their age, sex or occupational group a strong predictor of how committed an individual 1s.

The results of the work reported above have clear implications. It suggests that we cannot afford to make assumptions about those we work with or for. We cannot take for granted what other people involved in the procurement or management of the built environment believe about how the environmental performance of buildings should be improved, or think about how construction should be made more ‘sustainable’. Their motives and aspirations for acting, and the narrowness or breadth of their agendas, are not necessarily compatible with ours. So for effective interactions we need to make clear:

- where we each stand on these issues
- how much common ground we and those we are working with occupy, and
- where and when we need to disagree amicably if progress is to be made.

3.0 Encountering difference in the design and procurement process

In practice also, there are many types of difference (such as values, priorities, time horizons, etc) which act as barriers to the implementation of change. These have previously been identified in the area of new environmental technologies. Gilham [6] identified key barriers which arose owing to a range of differences. Key conflicts arising included:

- a reluctance on the part of funders to adopt innovative technologies until they know they work and unless they have a long term occupier/tenant appeal.
- a reluctance by all parties to try new ideas owing to the risk factor for a specific group.

These two issues are typical of a low-risk tolerant construction industry which is dominated by contractractual relationships. These are key issues raised in “Constructing the Team”, a review of the UK construction industry carried out by Latham in 1994 [1]. The longevity of the product (i.e. a building) is also a contributory factor giving rise to the paradox of a long term product stemming from organisations with short term business strategies. Further issues identified in the research included:

- an overwhelming misperception that the different parties involved in the construction process have insufficient knowledge of energy efficiency to specify what they want or give good advice.

- a lack of hard data in client organisations about capital and running costs associated with energy efficiency.
- an overestimation by designers of their potential influence on clients in relation to other parties. Issues that drive clients' decisions are not high on designers' priority lists. Therefore designers cannot always use their good understanding of energy efficiency to good effect when advising the client.

The appropriateness of the information for each of the groups in the process needs to be considered very carefully. BRE's experience with improving energy management [7] within organisations indicates that data and information is not easily transferrable between different interest groups. The diverse needs of financier, developer, architect, engineer, cost controller, project manager, supplier and researcher require specific consideration. Factors such as language, format, timescale, organisational and personal values, skills base and learning styles, all have an effect on the accessibility and relevance of the information to each user group.

4.0 Cultural dimensions - understanding difference.

Difference manifests itself in many ways. We have explored above how various factors impact upon attempts to bring about environmental improvements in construction. Here we consider the dimensions of culture as a source of that difference which affects the decision making priorities of the different organisations and professionals. We should consider how the unconscious application of peoples' different values, as the core element of their culture, often leads to the conflict and the subsequent lack of resolution, change and progress which are needed if we are to achieve sustainable development.

4.1 Culture

There are three basic elements to our human programming:

- human nature, which is universal and inherited
- personality, which is specific to the individual being partly inherited and partly learnt.
- culture, which can be described as being learnt and specific to a social group or category.

Cultural differences manifest themselves in many ways and in varying degrees of permanance, such as:

- symbols - words, gestures , pictures or objects conveying meaning which is recognised by those who share the culture
- heroes - persons dead or alive, real or imaginary, who possess characteristics which are highly prized in a culture
- rituals - collective activities, technically superfluous in reaching desired ends, but which within a culture, are considered socially essential.

These three layers can be grouped as "practices" which form the outer and more easily altered layers of culture. The inner core of culture is "values", described by Hofstede [8] as "broad tendencies to prefer certain states of affairs over others". The values which people hold determine how they approach the decision making process and also what outcome they will feel comfortable with. We can see how the "practices" can change over time both in a broad societal context and in the context of organisational cultures[9]. However, "values", the inner core, deal with issues such as: evil vs good; dirty vs clean; ugly vs beautiful; natural vs unnatural; normal vs abnormal; paradoxical vs logical; rational vs irrational. As they are amongst the first things we learn as children, they are the hardest to change with many remaining unconscious to those who hold them.

4.2 Measures of difference

People carry many layers of mental programming for the different groups in which they live and work. Layers of culture exist at national, regional or ethnic grouping , gender, generation, social class, and organisational levels. Systematic research on values is cumbersome and ambiguous. However, Geert Hofstede, Professor of Organisational Anthropology and International Management at the University of Limburg in the Netherlands, has carried out extensive research which has resulted in the identification of five key dimensions of culture:

- Power distance
- Masculinity/femininity
- Uncertainty avoidance
- Individualism
- Short and long term orientation

These were developed as part of a world-wide study [8] in over 50 countries during the mid eighties. Hofstede identified many characteristics typical to each of the dimensions. It is these characteristics which we will use as the basis of discussion and review for the differences which are being encountered in the building procurement process.

4.3 Issues of culture for discussion - mapping onto the identified difference

The power distance index is an indication of attitudes towards relationships with other people based on position and roles within society. It reveals the attitude towards authority and also of how people will be motivated or de-motivated by the dominance of power.

Cultures demonstrating a small power distance index will typically strive for: minimisation of inequalities; interdependence between less and more powerful individuals and organisations. They will prefer less heirarchical frameworks and will favour decentralisation with a range of people involved in the decision making process.

Conversely, cultures demonstrating a high power distance index will: feel more comfortable with inequalities in society; manage through heirarchical structures; be more directive and unwilling to discuss and share problem solving. Authority and centralisation will be popular.

Looking to the construction industry, we might identify design consultancies typifying the team approach to problem solving and having a small power distance index and major client organisations such as local authorities and MOD, as more heirarchical. Heirarchies also tend to develop in larger organisations and can be identified as the dominant structure for major contractors. A conclusion from this, which would be supported by many designers and was identified in [6], is that designers can often be excluded and alienated from key decisions made in the design and procurement process.

Differences described by the "masculinity/femininity" index typically manifest themselves in the workplace in the following ways:

- attitudes towards relationships - where the more feminine cultures value the maintenance of relationships over tasks and performance which are highly prized in masculine cultures
- attitudes towards conflict - where negotiation and compromise are key words typifying the approach in feminine cultures and conflict, "fighting them out", toughness, assertion and ambition are words which typify masculine cultures.
- attitudes towards decision-making - where masculine cultures demand facts and proof, whilst feminine cultures trust more in intuition and consensus

These differences are not specific to men and women. Instead they characterise approaches which are evident across the sexes such as in the researcher or financier who requires "evidence" and "proof' and the entrepreneur who follows his or her intuition. There is a very strong correlation between those nations which scored the lowest masculinity rating in Hofstede's research - Sweden, Norway, Netherlands and Denmark and those which are recognised as leaders in environmental improvement activities.

A culture with a strong uncertainty avoidance index is typical for many client groups of the construction industry. This index measures the ability to live with risk, uncertainty and change and could be usefully explored for the construction process itself which is structured to eliminate and penalise changes occuring during the process. Cultures with a weak uncertainty avoidance: require few rules; enjoy learning, discovery and innovation; tolerate deviation. However, the inherent insecurity in life is felt as a continuous threat for cultures with a strong uncertainty avoidance index. There is a fear of ambiguity, with an emotional need for rules and "right" answers to questions.

This characteristic, when combined with the masculinity/femininity characteristics, can lead to widely different approaches to innovation and change. Interestingly the four nations previously mentioned above all appear as low scorers on the uncertainty avoidance index (i.e. they tolerate uncertainty).

The "individualism index" measures collectivism, thinking in terms of "we",or individualism, thinking in terms of "I", within a culture. Differerences manifest themsleves in the workplace in a variety of ways. For collectivists identity is based on social networks; relationships prevail over task (links with femininity); with harmony preferred to direct conflict; management is management of groups; and the employer - employee relationship is perceived in moral terms, like a family link. For individualists: identity is based on the individual; speaking one's mind is revered; management is management of individuals and employer-employee relationships are supposed to be based on mutual advantage.

Short and long term orientation was the fifth dimension which Hofstede identified after studying more closely oriental cultures. Attitudes towards long and short term decision making could have the greatest impact on improving environmental performance in buildings and the achievement of sustainable development. The concept of "investing in the future" is central to definitions of sustainable development and lead to the paradox referred to earlier which is familiar to the construction industry, i.e. satisfying short term needs of clients with a long term product . Typical characteristics of short term orientation include: respect for traditions and social obligations with a need to "save face"; a pressure to "keep-up" even if overspending although investing minimally; quick results expected; and concern for possessing "the truth". Characteristics of a long term orientation are: adaptation of traditions for modern use with subordination to purpose; perseverence towards slow results, valuing investment; thrift - being sparing with resources; and respecting the demands of virtue.

5.0 Procurement practices - Value management and Partnering

For practitioners in construction procurement the demand for sustainable development brings about increasing complexity. "Culture", "values", "innovation", "change", are complex and emotive issues which often appear confusing and obstructive in the work place. However, largely driven by the demand for greater efficiencies and to improve the "customer focus" in the UK construction industry, Value Management and Partnering, have evolved which are now showing considerable benefits to the customers of the industry and members of the design and construction teams. These accommodate the diverse values of client design and construction teams and provide the basis for sustainable procurement practice.

5.1 Value Management

Value Management focuses on producing a better definition of the client's requirements. Value management should not be confused with value engineering which can be described as the provision of function at least cost. Value management requires that a careful analysis of "need" is carried out. Here all possible requirements of a client are considered prior to commencing the normal procurement process.(ie design, pricing, detailed design, construction) The benefit of this is that the full range of skills can be applied to finding solutions for the client. Priorities are defined - in terms of value and importance - and then design, procurement and construction solutions are applied to deliver those priorites throughout the development process. The structure allows for review and the introduction of changing priorities occuring during the process. Value Management is particularly applied to projects with high value and high strategic risk.

The key stage in Value Management is the beginning where, usually in a facilitated workshop environment, the customer and supplier teams combine to:

- share aims and aspirations
- share values and identify priorities
- identify shared and individual benefits
- define decision making protocols
- set and agree strategic objectives
- set and agree means of measurement of success, and
- establish the partnership.

5.2 Partnering

Partnering is a term which describes an approach to construction procurement which can (and often does) eliminate competitive tendering as part of the process. A partnership is built between customer and supplier(s) which can be strategic, ie set up with a long time horizon, or project-based (where the partnership is established for the duration of the project alone). Inevitably there is a process of comparison, often at the very outset of the process where clients make a selection of potential partners from a proposal or submission. However, selection criteria are a combination of cost, quality, approach, style and skill in partnering. One example of this approach is illustrated by Southern Water Services [10] for the selection of the project-specific partners for a major civil engineering project in the UK. Here, the selection procedure included a series of questionnaires, interviews and presentations which focused on the experience and culture of the organisations and the people rather than the fee rates.

There are three key elements which define "partnering". They are:

- mutual objectives - shared by the partners on both customer and supply sides.
- problem resolution - where a process of conflict resolution is agreed at the outset of the partnership
- continuous improvement - where partnership aims to learn and build its capabilities from one experience to the next. This element includes the process of evaluation, feedback and review.

Collectively, these three elements describe an approach to construction procurement which was encouraged by Latham and is being taken forward by the Construction Industry Board.

What the practices of value management and partnering do is provide a working framework in which the different values of the client and the procurement team can be harnessed to good effect. They are therefore a useful starting point to identify new ways of working that will accommodate the diverse values and needs of clients who demand a sustainable built environment.

6.0 Construction procurement - managing cultural change

Within the context of developing sustainable construction procurement practices, this paper has explored the links between environmental improvements in construction and the cultural dimensions and characteristics of those involved in the supply chain. The differences and conflicting views which are present throughout the construction supply chain act as substantial barriers to the application and development of environmental technologies, of new ways of working, and of general progress in tackling the more difficult issue of precisely what constitutes 'sustainable' construction.

Wide ranging and significant differences are encountered in the UK as elsewhere in Europe. Some sets of cultural characteristics appear more attuned to improving the environmental performance of buildings and to moving towards a sustainable built environment than others. Yet the significance of these characteristics, and the importance of deliberately trying to nurture them (especially where they are currently absent) is seldom discussed - particularly in discussions of what constitutes "sustainable" construction.

Cultural change has been formally recognised as essential in the UK construction industry in order to bring about improvements to its productivity, efficiency, quality and to reduce its costs. Fundamental cultural changes have been called for. Although these have not yet been achieved, new ways of working are emerging which can more easily accommodate the different (and sometimes opposing)values of clients, designers and construction teams. 'Value management' and 'partnering' are two approaches which can yield dramatic benefits for their practitioners, both customers and suppliers alike. These practices require that more time, effort and understanding is devoted to managing the cultural components and dimensions of construction procurement. Like any change process, movement towards sustainability is more likely to succeed if this process is explicitly managed.

In order to increase the chances of achieving sustainable construction, we need to recognise that the role of individual, group and national cultural characteristics deserves much more time, effort and understanding than we currently afford them. For successful developments, especially in the context of combating unsustainability, will need to consider the values, aspirations and motives of a broader range of players than traditionally has been necessary in construction procurement. These players will have to stretch beyond the individual project/client-base, as well as beyond the supply side of the individual design/construction team. Eventually, to match the principles underlying sustainable development, our construction procurement protocols will have to be capable of accommodating other (currently unrepresented) stakeholders, especially those involved in processes for regulating the production, maintenance and replacement of the built environment.

7.0 Acknowledgements

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8.0 References

1. Latham, M. (1994) Constructing the Team, Oxford Press, UK
2. Eclipse Research Consultants (1996) Environmental initiatives in the UK construction industry: 1995 survey of current practice, ERC, Cambridge, England.

3. Palmer, J., Cooper, I & van der Vorst, R. (1997) Mapping out fuzzy buzzwords - who sits where on sustainability and sustainable development, Sustainable Development, 5, 2, 87-94.
4. Mitchell. G., May, A.& McDonald, A. (1995) PICABUE: a methodological framework for the development of indicators of sustainable development, International Journal of Sustainable Development and World Ecology, 2, 104-123.
5. Eclipse Research Consultants (1996) PICABUE - mapping commitment to sustainable development: a self-assessment technique for policy-makers and practitioners, ERC, Cambridge, England.
6. Gilham A.(1997) Non-technical barriers to the implementation of energy and environmental design strategies, CIB, TG8 Conference proceedings, Paris.
7. BRECSU, (1993 - 1995) General Information Reports 12, 13 and 28, Good Practice Guides 85, 165, 167, 169, etc. Energy Efficiency Office Best Practice Programme, UK.
8. Hofstede G. (199 1) Cultures and Organizations, software of the mind - Intercultural Cooperation and its importance for Survival, McGraw-Hill, UK
9. Bates P. (1994) Strategies for cultural change, Butterworth Heinemann, UK
10. Contruction Industry Board, 1997, Partnering in the Team, Thomas Telford, UK.

Health and safety and the environment as project parameters

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Abstract
Traditionally, cost, quality and time have constituted the parameters within which projects have been procured and managed. This traditional approach has been perpetuated by inter alia: tertiary construction education, clients, designers, project leaders and the construction industry. However, the traditional approach has not been successful with the greater percentage of contracts not being completed within budget and to schedule and quality requirements. This non-realisation of the traditional project parameters (requirements) is largely attributable to the exclusion of health and safety and the environment which complement cost, productivity, quality and schedule as the result of the synergy between them. This synergy in turn is the essential catalyst for Total Quality Management (TQM) – the continual improvement of the construction process.

To this end the fmdings of various descriptive surveys conducted among general contractors and project managers will be presented which substantiate the synergy, inter alia: positive influence of health and safety on productivity, quality and the environment.
Keywords: Project parameters, health and safety, environment

1 Introduction

The traditional concern of designers and constructors has been the protection of constructed items from the effects of the environment. However, recently it has been realised that construction projects may have environmental implications from: the materials used; the nature of the design; the method of construction; the location and layout; the physical structure itself or the use to which it is put, and the effect of construction operations and products on the environment [1].

Occupational disease, fatalities and injuries are not project requirements and result in an increase in the cost of resources as a result of medical care, rehabilitation, compensation insurance, pensions payable in the case of fatalities and ancillary rework [2].

2 Statistics

Table 1 indicates the nature and extent of the injury problem in South African construction. It should be noted that occupational health and safety statistics are only available six years in arrears in South Africa.

Class of injury	Total No.	No./Class of injury/	
		Working day	R100m Construction completed
Fatalities	189	0,8	0,8
Permanent disablement	946	4,1	4,0
Temporary disablement	7 645	33,0	32,1
Medical aid cases	10 108	43,6	42,5

Table 1: Injuries per working day and per R100m (US$20,83m) construction completed in South Africa for the year 1990 [3] and [4].

Other salient statistics according to the Compensation Commissioner[4], Federated Employers Mutual Assurance (FEMA) [5] and the South African Reserve Bank (SARB) [3] are:

- The Disabling Injury Incidence Rate (DIIR) of 2,03 in 1990 means that 2,03 workers per 100 received disabling injuries [4].
- The Severity Rate (SR) of 3,86 in 1990 means 3,86 days were lost per worker [4].
- The total of 1 620 046 days lost as a result of fatal and non-fatal accidents in 1990 is the equivalent of 6 983 work days lost for every work day [4] and [5].
- The Fatality Rate in 1990 was 53,5/100 000 workers [4]. This does not compare favourably with the rates of selected countries for 1992: Japan (19); United States of America (18,6); Germany (14); Australia (11); Canada (7,4); Sweden (6), and The Netherlands (3,3) [6].

3 Reasons for considering health and safety

The reasons for considering health and safety are: the human factor; legislation; financial issues, inter alia, fines, cost of accidents and benefits of health and safety;

client pressure; cost of training replacement personnel; pending Construction (Design and Management) Regulations which will link clients and designers to site health and safety; attitudes of the court relative to liability of stakeholders in terms of comrnon law in the event of accidents, and the costs of reinstating the environment as a result of accidents [7].

4 Reasons for considering the environment

There are three reasons the industry needs to act: to pre-empt unfavourable consequences as a result of the increasing array of environment-related statutes, regulations and policies; to prepare for the changed nature of items it will be required to design, construct and manage, the new materials it might have to use and the processes it will have to adopt, and to contribute to overall environmental related efforts and issues [1].

Pitney [8] maintains the perception exists that the construction industry is insensitive to the environment, profit motivated and destroyers of the environment rather than protectors.

5 Health and safety and the environment

Environmental concerns are often interrelated with construction health and safety issues [9]. Unhealthy and unsafe practices, inter alia, concrete run-off or spillage, fires, oil spillage, waste and uncontrolled sanitation impact negatively on the environment. Generation of dust, hazardous materials and the release of non-biodegradable material into the environment contribute to the impact [10].

6 Cost of accidents

The cost of accidents can be categorised as being either direct or indirect. Direct costs tend to be those associated with the treatment of the injury and any unique compensation offered to workers as a consequence of being injured and are covered by workman’s compensation insurance premiums. Historical records can be reviewed to determine the amount of expenditure attributed to each particular injury. The indirect costs are those which are hidden and for which no historical record is kept. However, indirect costs are identifiable, but only ‘hidden’ in that they are not attributed to injuries in a bookkeeping sense [11]. Indirect costs include: reduced productivity for both the returned worker(s) and the crew or workforce; clean-up costs; replacement costs; stand-by costs; cost of overtime; administrative costs; replacement worker orientation; costs resulting from delays; supervision costs; costs related to rescheduling; transportation, and wages paid while the injured is idle. Various studies have realised differing ratios between the indirect and direct costs: 1,67 times for non-minor injuries and more than 5 times for minor injuries with direct costs less than US$50 [12], and 20 times [13]. Research indicates the total cost of accidents to constitute, inter alia, 6,5% of the completed construction [14] and approximately 8,5% of the tender price [15].

7 Environmental cost

The environmental cost resulting from the construction process and the built environment is substantial [1]. Much energy is used: in the production of materials such as cement, steel, aluminium, wood products, plastics and paints; the movement of materials and components to sites; the running and operating of plant and equipment on site and in the heating or cooling, or running of the machinery in completed buildings.

About 50% of atmospheric carbon dioxide is emitted from buildings and about 50% of all CFC's, which contribute to the long term depletion of stratospheric ozone as well as global warming, are used in building services as well as in insulation materials.

Sick Building Syndrome (SBS), where poor air quality, lighting and airborne pollution lead to various ailments and ultimately lost productivity among office workers. The annual loss in The Netherlands is estimated to be in excess of US$l billion.

Construction and human waste resulting from the construction process and the built environment respectively, result in, inter alia, the waste of land resources and contamination of natural resources and ecologies.

8 Synergy

A healthy and safe workplace complements cost, productivity, quality and the environment [10]. Hinze [16] maintains outstanding projects are: either ahead of or on schedule; within budget and reflect exemplary health and safety.

9 Benefits of health and safety

According to Pomfret [17] benefits include: less injuries; less property damage; less down time; improvement in morale; enhanced industrial relations; increased productivity; reduced cost, and enhanced quality. Other benefits include: less compensation insurance; fewer hidden costs; improved supervisor morale; increased efficiency, and improved marketability [18].

10 Project requirements/goals

According to Hinze [16] health and safety is vitally important, not just cost, quality and time because if a worker has been permanently disabled or killed, then a project is not a success. Total quality includes health and safety and all requirements are achievable concurrently. Levitt and Samelson maintain quality includes productivity and health and safety [18].

Successful project goals include environmental sustainability [19] and Ofori contends that the environment should be the fourth goal on construction projects [1]. Research conducted in the United Kingdom determined health and safety to be one of the five main criteria for contractor selection [20].

All the projects which received awards in the Australian Third Natural Excellence Awards for 'best practice' involved unique and special challenges, inter alia, stringent cost and time constraints, sensitive environmental issues and health and safety [21].

11 Research

The salient findings of a number of descriptive postal surveys conducted nationally among various survey populations in South Africa are presented.

11.1 General contractors

78 metropolitan area based general contractors who are members of the Building Industries Federation of South Africa (BIFSA) or the South African Federation of Civil Engineering Contractors (SAFCEC) responded to this survey to determine the influence of management on health and safety.

11.1.1 Most contractors viewed health and safetv to be important (Table 2).

Importance of Health and Safety	Response (%)
Verv	42.9
Important	44.1
Fairlv	10.4
Not	2,6
Total	100,0

Table 2: Importance of health and safety

11.1.2 The benefits of health and safety improvement were both quantitative and qualitative (Table 3).

Nature of improvement	Response (%)
Reduced accident costs	41,4
Increased productivity	37,9
Fewer complications	37,9
Workmen's compensation rebates	20,7
Other	10,3

Table 3: Benefits of health and safety improvement

11.2 Project management practitioners

47 members of the Project Management Institute (SA Chapter) responded to this survey to determine the role of project managers in contractor health and safety.

11.2.1 95,8% responded that inadequate or the lack of health and safety increased project risk. Accidents and disease result in variability of resource which in turn increases project risk.

11.3 General contractors

71 metropolitan area based general contractors who are members of BIFSA and SAFCEC responded to this survey to determine the influence of clients on contractor health and safety.

11.3.1 Table 4 schedules the project priorities of clients as perceived by contractors. The environment, and health and safety were identified least and second least frequently respectively.

Aspect	Priority Ranking (%)				
	Very	Fairly	Not	Don't know	Total
Cost	90,1	5,6	0,0	4,3	100,0
Environment	11,6	63,3	18.8	7,3	100,0
Health AND safety	25,7	45,7	22,9	5,7	100,0
Productivity	46,4	27,5	23,2	2,9	100,0
Quality	90,0	5,7	1,4	2,9	100,0
Schedule	66,2	25,0	0,0	8,8	100,0

Table 4: Client project priorities as perceived by contractors.

11.4 Project management practitioners (PMP) and general contractors (GC)

11.4.1 Relative to the aspects negatively affected by inadequate health and safety, the consolidated responses emanating from the surveys presented in 11.2 and 11.3 above are presented in Table 5.

Aspect	Yes Response (%)	
	PIMP	GC
Cost	72,3	81,2
Environment	66,0	58,5
Productivity	87,2	87,1
Quality	80,8	82,4
Schedule	57,4	-*
Client perception	68,1	77,6
Contractor image	-*	86,8

Table 5: Aspects negatively affected by inadequate health and safety.
* Not asked

12 Conclusions

Accidents result in fatalities, injuries, disease and damage to the environment and do not constitute project requirements.

The traditional project requirements of cost, quality and schedule are marginalised by inadequate health and safety and concern for the environment. The benefits of prioritising health and safety and the environment include reduced cost, enhanced productivity and quality, earlier completion and customer satisfaction.

13. Grossman, D. (199 1) Construction industry builds a safe workplace. *Safety and Health,* April. pp. 48 - 51.
14. The Business Roundtable. (1982) *Improving Construction Safety Performance,* The Business Roundtable, New York.
15. Anderson, J. (1997) The problems with construction. *The Safety and Health Practitioner,* May. pp. 29 & 30.
16. Hinze, J.W. (1997) *Construction Safety.* Prentice-Hall, Inc., New Jersey.
17. Pomfet, B. (1997) Psychology of Safety. *National Safety,* May/June. pp.14&15.
18. Levitt, R.E. & Samelson, N.M. *Construction Safety Management.* 2nd Edition, John Wiley & Sons Inc., New York.
19. Dreger, G.T. (1996) Sustainable development in construction: Management strategies for success. *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernization and Education,* Beijing, October 1996, CD-file:///D1/papers/160-169/163/p.163.htm
20. Hatush, Z. and Skitmore, M. (1997) Criteria for contractor selection. *Construction Management & Economics,* Vol. 15, No. 1, pp. 19-38.
21. Chartered Building Professional. (1996) Building one of only five best practice industries. *Chartered Building Professional,* November, p.6.

13 Recommendations

Health and safety and the environment should be included as project parameters. Inclusion as project parameters implies that: they be considered during all phases of a project; procurement systems be suitably structured, and practices are implemented to engender health and safety and sustainability of the environment.

14 Acknowledgements

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15 References

1. Ofori, G. (1992) The environment: the fourth construction project objective? *Construction Management & Economics*, Vol.10, No. 5, pp. 369-395.
2. Smallwood, J.J. (1996) The role of project managers in occupational health and safety. *Proceedings of the 1st International Conference of CIB W99 – Implementation of Safety and Health on Construction Sites*, Lisbon, September 1996, pp. 203 – 213.
3. South African Reserve Bank (SARB). (1991) *Quarterly Bulletin 1990*, SARB, Pretoria.
4. Compensation Commissioner *(CC).* (1995) *Report on the 1990 Statistics, CC,* Pretoria.
5. Federated Employers Mutual Assurance Company Limited (FEMA). (1994) Personal contact: Mr D. Joss.
6. Center to Protect Workers' Rights (CPWR). (1997) *The Construction Chart Book. The U.S. Construction Industry and Its Workers*, CPWR, Washington.
7. Meere, R. (1990) Building can seriously damage your health. *Chartered Builder*, December. pp.8&9.
8. Pitney, S. (1993) The greening of the construction industry. *The Building Economist,* September. pp.1 1-14.
9. Coble, R.J. & Kibert, C.J. (1994) The environment as a construction safety concern. *Proceedings of the 5th Annual Rinker International Conference focusing on Construction Safety and Loss Control,* Florida, October 1994, pp. 535 – 542.
10. Smallwood, J.J. (1995) *The influence of management on the occurrence of loss causative incidents in the South African construction industry.* MSc Dissertation. University of Port Elizabeth, Port Elizabeth.
11. Hinze, J. (1994) Quantification of the indirect costs of injuries. *Proceedings of the 5th Annual Rinker International Conference focusing on Construction Safety and Loss Control,* Florida, October 1994, pp. 521 – 534.
12. Hinze, J. (1992) Indirect costs are a major portion of job site injury costs. *Concrete Construction,* March. p. 229.

Project Performance and Conflict Avoidance: A front-end approach

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Abstract

Building construction projects tend to perform poorly; most run over budget, lag behind schedule, and often terminate in litigation before courts of law. In order to improve the performance of the building projects and to minimize claims (the two faces of the same coin), the strategic decisions taken up front by the building owner need to be improved. These decisions constitute the building procurement strategy; they establish the contractual framework for any project.

Different procurement strategies are now available for an owner when he or she wishes to select an approach to project delivery; each strategy is better suited for some aspects of typical clients' demands, whilst being weaker on others. In selecting a specific approach to procurement, very little attention is- paid to the likely effect of conflicts and their associated claims on the time and cost performance of the project.

This paper reports the findings of a research [1] undertaken within the IF Research Group to assess the impact of procurement strategies on conflict; jurisprudence is consulted for delay-related claims: their frequency, their dollar amounts, and the time lost in settling them. The root causes of time-related claims occurring under different procurement strategies are discussed.
Keywords: Building procurement strategies, claims, delays, project environment, project performance,

1 Introduction

Given the varied scenarios of project procurement strategies now available, selecting the best performing project *organizational* strategy still is, or should be, the highest priority for the building client. Because procurement strategies establish the framework for the various contracts betweenthe building owner and the members of the building team, it is hypothesized that the level of project performance is reflected - inversely - in the number and the extent of claims that arise. More specifically, this research examines claims arising from delays, and relates them to procurement strategies, particularly in instances where project time is found to be an important consideration for the building owner.

2 Project environment

For a long time, construction projects were managed and controlled according to rigid organizational structures based upon institutionalized roles. Modern organization theories such as contingency theory [2] and systems analysis [3] have established that project organizations need to be flexible, dynamic and responsive to the environment in which they operate.

A building project has three environments: the External environment which includes socio-economic considerations and particularly the contemporary concern for sustainable development in one form or another; the Industry environment or the overall state of the building sector, typically the linkage between supply and demand for man-made environment or building space; and the Internal environment which includes the specific constraints under which a building project comes to life, in other words, how the particular building process is organized and how efficient it is likely to be. It is well known that the elements of the building industry are diverse: owners - the demand side - with their different profiles, and architects, engineers, contractors, sub-contractors, suppliers and manufacturers - the supply side [4].

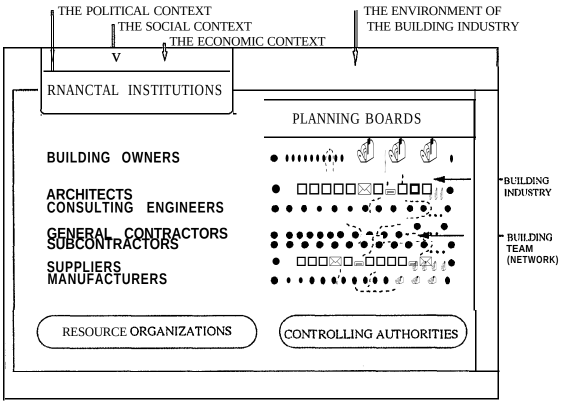

Figure 1: Building project as a temporary multi-organization [5]

The Building owner, although shown within the industry, belongs to a system of his own which is mostly external to the industry; he or she has functions and interests quite distinct from those of the industry, yet of necessity becomes closely involved with the building process* wherever a building is needed.

3 Project performance

Building project performance is defined as [1]:

> *" The effectiveness of the process, throughout its duration, in utilizing the available resources to satisfy the building owners' requirements and activities and to meet their constraints; and which results in the maximum collective benefit to all the participants without resorting to exploitation within the prevailing environmental conditions".*

The term "Performance" is thus understood to involve all aspects of the building process; these are productivity, timeliness, safety, quality and risk. These aspects are not mutually exclusive; each impinges on the others.

There is the wide-spread notion that for a project to be successful, it has to meet the owner's requirements of time, cost and quality. This view only reflects the short-term objectives of the team that is responsible for the project whilst neglecting the long-term objectives of each participating task-organization as it strives to survive in the marketplace. As result, a situation that requires joint decision-making is transformed into a kind of contest to claim greater bargaining powers. This situation is known, in management circles, to be an incubator for "inter-organization conflict", where inter-organizational conflict is manifested in disputes, which if remain unsolved, lead to claims. Claims are cumbersome to projects and affect inversely their performance.

To study the performance of different procurement strategies, one can explore the inherent problems and identify the root causes of inter-organizational conflict. Furthermore, it is logical to examine how they are reflected disputes and claims.

4 Claims and delays

There is abundant evidence in the literature concerning the severity of construction claims. According to Statistics Canada [6], about $94 billion have been spent on construction projects in 1993, which amounts to almost 13.5% of the Gross Domestic Expenditure. Based on the Rose report [7], a 20% increase in project cost can be attributed to claims; this means that the cost of claims alone amounts to approximately $18.8 billion - up 75% from 1990.

Goldsmith [8] defines a ***claim*** as "the demanding of something rightfully due to one". ***A contractual claim*** [9] is a written notice from either party to the contract (owner or contractor) to the other party requesting a relief (i.e. an extension of time or additional payment) due to unforeseen conditions, changes to the work, or interpretations of the contract.

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*). In this paper, the term "building process" is used to describe the whole process from perception of the need to the occupancy of building by the owner [Davidson, 1988].

According to Bramble and Callahan [10], ***delays*** are defined as “the time during which . some part of the construction project has been extended or not performed due to an unanticipated circumstance”. Construction claims due to delays are among the most complicated and difficult to analyze; sometimes they overlap with others and are then known as concurrent delays. Determining the *origins* of each delay and its impact on the project, and, even more importantly, the *responsibility* for the delay, can easily lead to conflict and thence to claims. According to Rubin et al. [11] delays can be classified as:

i- Excusable delays, (unforeseen by the contractor); they can be either Compensable (caused by owner), or Non Compensable (Force majeure);

ii- Non Excusable delays (caused by contractor or sub-contractor); the owner is entitled to delay damages.

However, when claims arise, the need to resort to such extreme action as litigation or arbitration demonstrates a *failure of* the contractual process. Any attempt to control this process should use the “frontal navigation” approach, setting the control from the outset and, hopefully, eliminating undue problems along the way. One way of doing just that is to select an appropriate procurement strategy that is associated with minimum delays and disruptions.

5 Research methodology

One hundred and twenty one cases of litigated time-related claims were analyzed. Only ***litigated, excusable and compensable delay claims*** were considered since they represent the worst case scenarios, are documented and traceable, represent facts-based judgements, are not biased by subjective opinions and have a direct impact on the project time and cost.

The procurement strategies adopted for the cases were classified according to Masterman’s [12] categorization [separated and co-operative (or “traditional”) procurement strategy (62 cases), integrated procurement strategy (47 cases) and management-oriented procurement strategy (12 cases)]. Other variables were identified: the type of owner procuring the project, the type of contract, the type of building, the time the project was delayed (expressed as a % of the planned duration of the project), the claimed amount, the awarded amount (expressed as a % of claimed cost to the initial project budget and a % awarded to initial project budget) and the trial time (time before the court decision, expressed as a % of the planned duration of the project).

Causes of claims were identified and grouped into three main categories that coincide with inter-organizational conflict-inducing factors (domain consensus, availability and access to information, and coordination). These causes have been found to be deterministic of the performance of the building process [13], thus enabling us to link claims to the inter-organizational conflict-inducing factors and thence to the performance of the building process.

A survey of all projects in the Montreal Metropolitan area procured during a given period was used as a control group.

6 Research findings

6.1 Claims occurrences

The *separated and co-operative* procurement strategy still appears to be the preferred strategy for public owners in procuring building projects and has a lower occurrence of claims than the other two procurement strategies. This is not surprising considering that it is the one which has been used the longest and that contract documents have been fine-tuned and standardized for its usage. The private owners also appear to have mastered the separated and co-operative procurement strategy and face even fewer claims under this strategy than public owners.

While the *integrated* procurement strategy, with its main variant design-build, has been gaining much support lately and is being presented as the panacea to all the problems of the construction industry, *our findings prove the opposite.* Both public and private owners have a high incidence of claims under this procurement strategy.

The *management-oriented* procurement strategy also appears more often in claims cases than its usage.

6.2 Claims outcomes

The *separated and cooperative* procurement strategy proved to be the best strategy in terms of all the claims outcomes for the private owner while being the second best strategy in terms of all the claims *outcomes* for the public owner (Table 1 and Table 2).

Table 1: Consequences for *public owners* under different procurement strategies (from the owner's point of view)

PROCUREMENT STRATEGY	% Time Overrun			% Claimed to Budget			% Awarded to Budget			% Awarded to Claimed			% Trial Overrun		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Separated and cooperative Strategy		▒			▒			▒			▒			▒	
Integrated Strategy	■			■			■					▒	■		
Management-Oriented Strategy			▒			▒			▒	■					▒

Table 2: Consequences for *private owners* under different procurement strategies (from the owner's point of view)

PROCUREMENT STRATEGY	% Time Overrun			% Claimed to Budget			% Awarded to Budget			% Awarded to Claimed			% Trial Overrun		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Separated and cooperative Strategy	■				▒		■			■				▒	
Integrated Strategy		▒		■				▒			▒				▒
Management-Oriented Strategy			▒			▒			▒			▒	■		

For the public owner the *integrated* procurement strategy generally proved to be the best strategy in terms of all the claims outcomes. The *management-oriented procurement strategy* generally proved to be the worst strategy in terms of all the claims outcomes for both the public and the private owners.

A synthesis of the consequences for each type of owner under each of the three families of procurement strategies is shown in Table 3.

Table 3: Overall performance of the different procurement strategies, from the owner's point of view

PROCUREMENT STRATEGY	PUBLIC OWNER						PRIVATE OWNER					
	Claims Occurrence			Claims Outcomes			Claims Occurrence			Claims Outcomes		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Separated and cooperative Strategy	■				▒		■			■		
Integrated Strategy			▒	■					▒		▒	
Management-Oriented Strategy		▒				▒		▒				▒

An examination of the synthesis shown in Table 3 indicates that there is a divergence between the occurrences of claims and their outcomes (e.g. the public owner under the integrated procurement strategy has a high claims occurrences but' has low claims outcomes). This suggested that an in-depth study of the root causes of claims would be useful.

6.3 Causes of claims

Twenty-two causes of claims were cited in the 12 1 claims cases in 241 instances (sometimes there were more than one cause per claim). Based on the factors in organizational design theory that were found to be conflict-inducing in multi-organizations, and were proven to be deterministic to the performance of the building project [13], the causes of delays were grouped into three main categories:

1. **Scope of the project (or domain consensus):** 5 causes of claims (changes in scope of work, changes of specifications by A/E, differing site conditions, misinterpretation of documents by A/E and excessive interpretation of documents) - evenly distributed among public and private owners (13 instances each) - were cited under this category in 26 instances;
2. **Availability and access to information:** 9 causes of claims (ambiguous documents, faulty specifications, incomplete documents, late approvals, late documents, late issuance of design documents, late rectifications, untimely and uncoordinated change orders and untimely design revisions) - 92 instances for public owners and 50 instances for private owners - were cited under this category in 142 instances;
3. **Coordination (or interdependence of tasks):** 8 causes of claims (lack of coordination, restricted site and interference, delayed site access, acceleration,

winter work, lack of site supervision, disruption by A/E and payment delay) - 46 instances for public owners and 27 instances for private owners - were cited in 73 instances.

A detailed analysis of the different causes of claims under the three families of procurement strategies and the two types of owners (public and private) revealed:

In the <u>scope of the project</u> category, all types of owners run into more problems when integrated and management procurement strategies are adopted, particularly regarding (i) changes in scope of work, (ii) differing site conditions and (iii) excessive interpretation of specifications;

In the <u>availability and access to information</u> category, all types of owners face numerous claims stemming from untimely and uncoordinated change orders; problems also arise from faulty or late documents in the traditional and integrated approaches to procurement; this category of causes underline the majority of claims cases - 58.92%;

In the <u>coordination</u> category, private owners fare better than their public counterparts, but for both, lack of coordination and restricted site and interference cause a number of problems.

7 Conclusions

The discourse concerning delay-related claims is not very different from that on inter-organizational conflict and the performance of the building process from the point of view of the availability and access to information. A systematic effort to co-ordinate information management appears to be a prerequisite for success, and particularly for the successful introduction of innovation or changes in the building process and for the improvement of the performance of the process itself.

Meanwhile, our findings point to the consequences (in terms of claims) of the constraints within which public sector owners operate. They also throw an unexpected light on the likelihood of all types of owners running into trouble when non-traditional procurement strategies are adopted, suggesting the need to fine-tune the practicalities of these strategies.

Surprisingly, the management-oriented procurement strategy proved to be the worst strategy for both types of owners. The introduction of a new party (the construction manager) into the traditional project team appears to pose a problem of integrating another party into the classic “team” of designers and constructors.

The separated and co-operative (or traditional) procurement strategy still is the preferred strategy and has less occurrences of claims with less impact on time and cost of the project. Innovative procurement strategies proved to be in a bad position compared to the traditional procurement strategy. The possible explanation of this result is that the innovative procurement strategies (integrated procurement strategy and management-oriented procurement strategy) are relatively new, comparatively untried and obviously require further development in order to iron out contractual and other kinds of problems.

While the choice of a procurement system cannot be based merely on the potential to minimize unhealthy disputes and litigation, this criterion can be incorporated as one of the criteria to be considered when selecting an appropriate procurement system.

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9 References:

1. Abdel Meguid, T.A. (1997). *Managed Claims' Procurement Strategy (MCPS): A Comparative Study of the Performance of Alternate Building Procurement Strategies.* Unpublished Ph.D. Thesis, Faculté de l'Aménagement, Universite de Montreal, Montreal, Qc., Canada.
2. Lawrence, P.R., and Lorsch, J.W. (1967). *Organization and environment: managing differentiation and integration.* Harvard; Harvard Business.
3. Cleland, D.I. and King, W.R. (1975). *Systems analysis and project management.* 2nd edition. McGraw-Hill Book Company, N.Y.
4. Katsanis, C. J., and Davidson, C.H. (1996). "Horizon 2020: Building Procurement and Industry Fragmentation, A North American Scenario." in Taylor, R., (ed.), *North meets South - Procurement Systems Symposium, CIB W92 Proceedings,* South Africa, Natal, Durban. pp. 251-260.
5. Davidson, Colin H. (1988). "The Building Team," in Wilkes, J.A., and Packard, R.A., (eds.), *Encyclopedia of Architecture: Design, Engineering and Construction, New* York, John Wiley and Sons, pp. 509-515.
6. Statistics Canada, (1991-1994). Construction in Canada, Catalog no. 64-20 1.
7. Rose, G. (1991). *Alternative dispute mechanisms and contract settlement: Secretarial report,* Construction Industry Development Council, Ottawa, Ontario, Canada.
8. Goldsmith, I. (1983). Canadian Building Contracts. (2nd ed.) Carswell: Toronto.
9. Abdel Meguid, T.A., and Davidson, C.H. (1996). "Managed Claims Procurement Strategy: A Preventive Approach." in Taylor, R., (ed.), *North meets South - Procurement Systems Symposium, CIB W.92 Proceedings,* South Africa, Natal, Durban. pp. 11-20.
10. Bramble, B.B., and Callahan, M.T. (1987). *Construction Delay Claims.* John Wiley and Sons Inc., New York, N.Y.
11. Rubin, R., Guy, S., Maevis, A., and Fairweather, V., (1983). Construction Claims Analysis, Presentation, Defence, Van Nostrand Reinhold Co., New York.
12. Master-man, J. W.E. (1992), *An introduction to building procurement systems,* E & F.N. Spon Ltd.
13. Mohsini, R.A. (1985). *Building Procurement Process: A Study of Temporary Multi-Organizations.* Unpublished PhD Thesis, Faculte de l'Aménagement, Universite de Montreal, Montreal, Qc., Canada.

ATTITUDES TO UK CONSTRUCTION PROCUREMENT SYSTEMS FOR REFURBISHMENT WORK

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Abstract
This paper reports some of the findings of a study on construction procurement systems for refurbishment works which involved **86** postal questionnaires completed by key personnel from client's representatives (architects, quantity surveyors), contractors and other consultants from specialist and general UK refurbishment organisations. This was augmented by 10 semi-structured interviews conducted with directors of construction refurbishment organisations. The study addresses, ***inter-alia,*** the frequency of use of procurement systems for different sizes and types of refurbishment projects; appropriateness of different procurement systems for refurbishment works, and the variety of factors affecting clients' choice of procurement systems for refurbishment works. It is suggested that the majority of refurbishment projects are still procured via the Traditional route, the main reasons being price competition and price certainty. Similarly, the inherent risks associated with refurbishment works are not given due consideration in the choice of procurement route. There is little, if any, authoritative guidance documentation on the selection of appropriate construction procurement systems for refurbishment works, yet evidence from this study suggests that there is an urgent need for guidance documentation. The challenge, therefore, is for the industry to produce guidance documentation on selection criteria and practices for procuring works in this very important sector of construction - the refurbishment sector.
Keywords: Contract, construction procurement system, professional attitudes, refurbishment works.

1.0. **Introduction**

Few will argue that matching the right procurement system with the right type of project to be carried out by competent professionals will benefit the client, the consultants and the construction industry as a whole. Construction procurement routes have received a wide coverage in the literature [1]. Similarly, studies have been conducted in order to improve the industry's awareness in selecting construction procurement systems [2]. In the main, however, these studies have been on new build works with very little attention being given to the refurbishment sector. In looking into the future direction of the UK project procurement, Hamilton (1990)[3] suggests that the client body is not yet fully satisfied with the services offered by the industry, and that there are likely to be more variations in the basic range of procurement systems. Hughes (1992)[4] is also of the view that 'the construction industry and its clients are still trying to sort out reliable methods of procuring construction'.

In his article entitled "Contractual terms for property maintenance and refurbishment projects: Their development, selection and interpretation", Robinson (1990)[5] argued that the standard form of contracts developed for new build applications have little relevance to the complexities and diverse nature of works on existing shells'. A thorough review of literature in the general areas of refurbishment [6, 7] would suggest that there is little or no authoritative guidance documentation on selection criteria and practices for procuring construction refurbishment works.

2.0. Methodology

The carrying out of the study was premised by the fact that a thorough literature review revealed that little or no empirical study has been conducted in the UK, in the past five years, in the area of construction procurement systems for refurbishment. It was therefore important to understand the current industry's attitudes to procurement systems for refurbishment works.

The study on which this paper is based was conducted between February and August 1997. From 250 postal questionnaires sent out, a total of 86 usable questionnaires from building contractors, architects, quantity surveyors, building surveyors and other consultants were received. Table 1 presents a frequency distribution of the postal questionnaires received by types of construction organisations. In addition, 10 ethnographic interviews with directors of construction refurbishment organisations and archive documentation obtained from construction organisations form the database for the study. For this paper, however, only some of the information derived from the quantitative data will be explored.

Types of Organisation	Number	Percentage (%)
Building contractor	45	52.3
Architects	23	26.7
Quantity Surveyors	9	10.5
Building Surveyors	4	4.7
Other Consultants	5	5.8

Table 1: Respondents to postal questionnaire by type of organisation (N = 86)

3.0. The Nature of Refurbishment Works

In this paper, refurbishment means such works as improvement, adaptation, upgrading, renovation, rehabilitation, modernization, conversion, retrofit, and repair; carried out on existing buildings for a variety of reasons. This definition, however, excludes works carried out on a routine basis such as cleaning, painting and decorating, and also emergency maintenance work.

In 1970, the repair and maintenance sector which accommodates refurbishment works accounted for £1109m (or 22.46%) of the total UK construction output. By 1996 this figure had increased to £21087m (or 42.32 % of total construction output). Despite the growth and increasingly recognised importance of refurbishment, only a meagre amount of empirical studies have been conducted in the management domain and in the areas of construction procurement systems [6, 8]. In their review of what has been published in the international journal - Construction Management and Economics in the ten year period between 1983 and 1993, Betts and Lansley (1993)[9] noted that ' . . . given their importance in developed construction markets, the use, maintenance and refurbishment phases have received little attention".

Yet, some writers have argued that refurbishment work is less predictable than new-build work, with a higher level of risk and uncertainty [8, 10]. It has also been shown that tender bids for refurbishment works are more variable than new build works [11, 12]. There is also a higher incidence of variation orders in a refurbishment contract, and a tendency for the job to expand to meet the budget [13]. There are others who have suggested that refurbishment processes are more difficult to manage than new build works [6, 10, 14]. It is therefore important that some attention is levelled at the selection criteria and practices used for procuring refurbishment projects.

4.0. Construction Procurement for Refurbishment Works

Construction procurement in the context of this paper means the framework within which construction work is brought about, acquired or obtained.

The Royal Institution of Chartered Surveyors [15] in their publication entitled "Refurbishment and Alteration Work", noted that '... traditional bills of quantities prepared in accordance with Standard Method of Measurement, are generally not suitable for the average refurbishment project. Similarly, Hakman (1975)[16] has argued that the repair and alteration work '... have their own special problems and conditions which need to be addressed in the preparation of the bills of quantities '.

Fellows *et al* (1985)[17] are also of the view that a more participative and flexible approach to contractual arrangement and procedure are needed. Ferry and Brandon (1991)[18] advised that '... the uncertainties of refurbishment work mean that it will be almost impossible and, certainly inadvisable, to undertake the [refurbishment] project on the basis of lump sum competitive tenders for the works, and other more collaborative methods of procurement will have to be used; either cost-plus or some form of management contracting.

The meagre amount of empirical studies conducted in the areas of construction procurement for refurbishment works would appear to have been conducted over 5 years ago. The UK construction industry is a changing industry, and so is the refurbishment sector [8]. It is therefore important to understand the current views of the refurbishment sector on construction procurement systems. This is important, at least, for two main reasons, Firstly, for policy makers in construction and those involved in strategic management within construction organizations. Secondly, it will provide some useful information for the development of appropriate and authoritative guidance documentation for selecting procurement systems for refurbishment works.

5.0. Study Results and Discussions

This study sought to ascertain the current frequency of use of construction procurement systems for refurbishment works. The study revealed that four main procurement routes are used for refurbishment works. These are presented in Table 2 in decreasing frequency of use.

An inspection of Table 2 reveals that almost 80% of refurbishment projects are procured through the Traditional form of procurement method. The study also shows that Design & Build is the next favoured form of procurement route. According to this study, only 3% of refurbishment projects are procured using the Management Contracting route. Although not analysed in this paper, the study also investigated the relationships between sizes of refurbishment projects, types of refurbishment projects and the usage of procurement systems. The study also sought to ascertain the underlying reasons behind the usage and selection of construction procurement systems for refurbishment projects.

Construction procurement systems	Frequency (No.)	Percentage (%)
Traditional	68	79.0
Design & Build	9	10.5
Construction Management	6	7.0
Management Contracting	3	3.0

Table 2: The frequency of use of procurement systems

The selection criteria from the views of the 86 respondents who participated in the questionnaire phase of the study are listed in Table 3 in decreasing level of importance for the most used procurement systems.

Rank	Traditional	Design & Build
1	Price competition	Risk avoidance and responsibility
2	Price certainty	Price certainty
3	Quality level	Quality level
4	Risk avoidance and responsibility	Speed of construction
5	Speed of construction	Price competition
6	Control of variations in the project	Control of variations in the project
7	Reserving client's right to alter specification	Clarity of client's contractual remedies
8	Dealing with complexity of projects	Involvement of client in construction process
9	Involvement of client in construction process	Reserving client's right to alter specification
10	Familiarity of procurement system	Dealing with complexity of projects
11	Clarity of client's contractual remedies	Familiarity of procurement systems
12	Separation of design from management	Separation of design from management
Rank	**Construction Management**	**Management Contracting**
1	Quality levels	Speed of construction
2	Reserving client's right to alter specification	Risk avoidance and responsibility
3	Control of variations in the project	Price certainty
4	Dealing with complexity of projects	Control of variations in the project
5	Speed of construction	Quality level
6	Price certainty	Reserving client's right to alter specification
7	Price competition	Involvement of client in construction process
8	Risk avoidance and responsibility	Clarity of client's contractual remedies
9	Involvement of client in construction process	Dealing with complexity of projects
10	Clarity of client's contractual remedies	Separation of design from management
11	Familiarity of procurement system	Familiarity of procurement systems
12	Separation of design from management	Price competition

Table 3: Criteria for selecting construction procurement systems for refurbishment works

An inspection of Table 3 which is data from an aggregate level indicates that the relative ranking of selection criteria differs from one procurement system to another. For example, price competition and price certainty were cited by the respondents in this study as the two most important criteria for selecting the Traditional procurement route, whereas the two most cited criteria for choosing management Contracting for refurbishment works were speed of construction and risk avoidance and responsibility. Interestingly, familiarity and knowledgeability of procurement options was rated very low as a criterion for selecting procurement systems. It is therefore important that any authoritative guidance documentation for the selecting construction procurement systems for refurbishment projects takes due cognizance of the necessary weighting factors associated with types of procurement systems, the views of different groups of construction professionals associated with refurbishment works, sizes, types and nature of refurbishment projects.

The study also sought to ascertain the extent to which there is an urgent need for a guidance documentation for the selection of appropriate procurement system for refurbishment works. To this end, the vies of participants to the questionnaire phase of this study were sought on the extent to which they agreed or disagreed on the need for a appropriate guidance documentation, Table **4** presents the result of this study.

	Frequency	Percentage (%)
Strongly Agree	**22**	**25.6**
	42	**48.8**
Not Sure	17	19.8
Disagree	**4**	**4.7.**
Strongly Disagree	1	1.2

Table 4: Degree of agreement for guidance documentation on construction procurement for refurbishment works

An inspection of Table 4 reveals that whilst over 74% of respondents in this study either agreed or strongly agreed on a need for a guidance documentation, just under 2% showed strong disagreement. The challenge for the industry, therefore, is to produce an authoritative guidance documentation for refurbishment works that takes account of the vagaries of refurbishment processes.

6.0. Conclusions and Recommendations

A recent study on construction procurement systems for refurbishment work has been conducted. It shows that the Traditional form of procurement, Design & Build, Construction Management and Management Contracting are the favoured forms of contract for refurbishment work. Whereas as almost 80% of refurbishment works are procured through the Traditional route, only about 3% of refurbishment works are procured by Management Contracting. Twelve factors have been identified that impact upon the selection of procurement systems for refurbishment works. These include: price certainty, importance of these factors in the selection of procurement options differ from one procurement system to another.

There is little or no authoritative guidance documentation on selection criteria and practices for procuring refurbishment works, yet this study has show an overwhelming need for one. The challenge, therefore, is for the construction industry to produce one, Such documentation should be based on appropriate weighting factors which take due cognisance of different types of procurement systems, the views of different professionals associated with refurbishment works, sizes, types and nature of refurbishment works.

7.0. References

1. Franks, J. (1990), "Procurement in the 1990s", Chartered Quantity Surveyor, The Royal Institution of Chartered Surveyors, UK, February.

2. Skitmore, R.M. and Marsden, D.E. (1988), '*Which Procurement System? Towards a Universal Procurement Selection Technique", Construction Management and Economics, 6, pp. 71 - 89.

3. Hamilton., N. (1990), "A Review of United Kingdom Procurement Methods", Proceedings of the CIB-W92, procurement systems, 1 Oth- 13 th September, Yugoslavia.

4. Hughes, W. (1992), "Developing Construction Procurement Law", Proceedings of the 8th Annual Conference, ARCOM., 18th-20th September, Isle of Man., UK., pp. 97 - 110.

5. Robinson, N.M (1990), "Contractual Terms for Property Maintenance and Refurbishment Projects: Their Development, Selection and Interpretation", Proceedings of International Council for Building, CIB - W70 Building Maintenance Worldwide, 7th- 9th March, Singapore, vol 2, pp. 1253 - 1262.

6. Egbu, C. 0. (1994) " Management education and training for refurbishment work within the construction industry", Ph.D Thesis, Vols. I and II, Department of Civil Engineering and Construction, University of Salford, England..

7. Egbu, C. O., Young, B. A. and Torrance, V. B. (1996) "The procurement of project works in the ship refurbishment and construction industries", Proceedings of CIB W92 symposium North meets South: Developing ideas, 14 - 17 January, Durban, South Africa, pp. 130 - 140

8. Egbu, C. 0. (1997) "Refurbishment management: Challenges and opportunities". Building Research and Information, The International Journal of Research, Development and Documentation, Nov/Dec, Vol. 25, No. 6, pp. 338 - 347

9. Betts, M. and Lansley, P. (1993) "Construction Management and Economics: A review of the first ten years", Construction Management and Economics, Vol. 11, No. 4, pp. 221 - 245.

10. Construction Industry Research and Information Association (CIRIA, 1994) "A guide to the management of building Refurbishment", Report 133, CIRIA, UK.

11. Chartered Institute of Building (CIOB) (1987) "Code of estimating practice", Supplement No. 1, Refurbishment and Modernisation, December, UK.

12. Quah, L.K. (1992), "Competitive Tendering for Refurbishment Work", Building Research and Information, Vol. 20, No. 2, March/April, pp. 90 - 95.

13. Quah, L.K. (1986), "Contact Documentation for Reducing Variability in Refurbishment Work", CIB, 10th Triennial Congress, Washington, USA, 22-26 September, Vol. 9, pp. 3916 - 3923.

14. Egbu, C. 0. (1995) “Perceived degree of difficulty of management tasks in construction refurbishment work”, Building Research and Information, vol. 23, No. 6, pp. 340 - 344.
15. Royal Institution of Chartered Surveyors (1982), “Refurbishment and Alteration Work”, Quantity Surveying Documentation, R.I.C.S., October, UK
16. Hakman, I. (1975), "More Rational Alteration Work", Report R14, National Swedish Building Research.
17. Fellows, R.F.; Newcombe, R. and Langford, D.A. (1985), “Client Control of Commercial Refurbishment Projects”, Final Report of a pilot study sponsored by the Science Engineering Research Council (SERC), Grant No. GR/D/10923, December.
18. Ferry, D.J. and Brandon, P.S. (1991), "Cost Planning of Refurbishment and Repair Work”, In Cost planning of Buildings (Eds. Ferry, D.J. and Brandon, P.S.), Chapter 19, pp. 247 - 250, Sixth edition, BSP Professional Books, Oxford, UK.

Environmental risk assessment of private finance initiative projects

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Abstract

The Private Finance Initiative (PFI) is a recent procurement strategy in the UK for bringing the private sector's fmancing ability, management skills, and expertise into the provision of public sector facilities and services. It is intended that this will promote significant risk transfer to the private sector and achieve value for money in the provision of assets. The Government has identified six principal risks relevant to PFI schemes which must be allocated to the appropriate parties. These include environmental risks as part of regulation and legislation principal risk.

Under PFI, the private sector has more responsibility than before to attend to changing environmental risks regulations, laws and directives from the European Union, UK Acts of Parliament and Organisation for Economic Co-operation and Development (OECD) policy. The PFI consortium (contractors, lenders, investors) have to date shown little regard to environmental issues associated with PFI schemes. It is argued that this could be as a result of the structure and culture of the construction industry which approaches risk in a fatalistic or reactive way rather than proactive or holistic. It is reckoned that there is need for a more satisfactory assessment of the costs of all environmental risks at all stages of contract negotiations and operation. The basic steps in environmental risk assessment in the processing industry sector are risk identification, risk evaluation, risk prevention and loss control, and risk fmancing and effective monitoring. The paper presents some techniques currently being used at all stages of environmental risk assessment in the processing sector for adoption by the construction industry.

Keywords: Environmental risk, environmental risk impact, private finance initiative, risk analysis techniques, sustainable development, environmental legislation.

1 Introduction

One of the major changes occurring in the decade is that businesses have begun to realise that the natural environment is an important part of the business environment [1],[2]. People are now beginning to show more concern than before for their environment in terms of health, safety, global warming, environmental degradation, threats to Earth's ozone layer etc. The level of community concern and outrage about their environment is unprecedented.

Achieving high quality environmental performance and taking a proactive position is becoming a factor for business not just for future commercial success but also for survival. The construction industry, like other sectors of the economy, faces much more environmental scrutiny and regulations, which implies that the industry must take more responsibility for environmental protection. Further, the integration of environmental concerns into sectoral decision making is now considered a key to improving environmental performance and moving towards sustainable development. Within the European Community, authority for environmental protection which is contained in the Treaty of Rome is based on the need to protect the environment, human health and natural resources [3].

Environmental risk assessment is applicable in cases where the use of land, building or facilities causes disturbances to the environment through air pollution, noise, vibration, intense lights etc. Environmental risks can differ depending on the sector of the economy. For example, Wilson [4] looks into this from a chemical processing perspective in terms of the presence of substances such as asbestos, chlorofluorocarbons, polychlorinated biphenyls etc and the impact the associated risk could have on the value of stakeholders interests (e.g. property owners, financial institutions, occupants, neighbours, regulators etc.). Root [5] looks at environmental risk in terms of risks associated with the transactional environment (consisting of actors such as customers, suppliers, banks, competitors etc. that a company interact or transacts with in a direct way) and the contextual environment (political, economic, technological, social-cultural etc.).

In general, significant damage to the environment is caused by three business sectors namely the municipal sector, the construction sector, and the processing sector [6]. In the construction industry environmental damage could take the form of environmental impact from blasting operations, air pollution caused by demolition or painting work etc. Pasquire [7] identifies environmental issues in construction including environmental legislation affecting the UK construction industry. The report concludes by calling for more research to provide qualitative and quantitative data and develop formal procedures for the procurement and management of environmental issues in construction.

This paper presents on-going environmental issues research which forms part of a larger research project on the Private Finance Initiative being undertaken at Glasgow Caledonian University.

2 Statutory Sources of Environmental Risks and Financial Exposure

Companies in the UK are now subjected to a wide range of environmental laws, regulations and directives; the majority of which emanated from the European

Community / European Union (EC/EU). Writing in 1989, Johnson and Corcelle [8] observed that over 100 legislative acts relating to all aspects of the environment has been adopted by the EC. There are currently more than 33 items of EU environmental legislation which can be grouped into seven categories: General Environmental Policy Regulations; Air; Chemical, Industrial Risks and Biotechnology; Nature Conservation; Noise; Waste and Water [9].

The 1990s, in particular, have witnessed greater emphasis on the environment within EC/EU policy making with the introduction of the concept of sustainable development in the 5th Environmental Action Programmes [10]. The 5th EAP differs from its predecessors in that it requires a longer term focus in terms of environmental objectives, seeks a greater understanding of the nature of risks to the environment, and advocates a mix of instruments designed to achieve policy objectives.

CIRIA [11] and Pasquire [7] have both listed the main UK Acts of Parliament affecting the UK construction industry. Some of these are in response to the EC/EU environmental legislations and directives [4]. Also the UK is responsible to the Organisation for Economic Co-operation and Development (OECD) environment policy which is monitored through the OECD environmental performance reviews. The main theme of the review is the reduction of the pollution burden, conserving nature and integrating environmental concerns in economic and sectoral decisions [12]. A full discussion of the implications of environmental legislation for the property and construction industries can be found in Lizieri *et al* [13]

In terms of financial risk exposure from short and long term environmental issues, Baker [14] recognises some potential sources namely: major environmental capital expenditures; increased costs associated with greater commitment to environmental management programmes; financial needs for acquisitions and divestitures arising from environmental liabilities; and reserves for adverse environmental-related contingencies.

A major financial risk leading to environmental capital expenditure is the possibility of a company being required to commit substantial funds to comply with environmental laws and regulations [15]. Company-caused environmental problems could lead to litigation including tort liability, class action suits, and victim compensation for personal injury or property damage based on the principles of strict, joint and several liability [14]. It is reckoned that financial risk exposure due to environmental issues deals with costs associated with environmental problems prevention, restoration and compensation [16].

In respect of construction, recent events such as the Manchester Airport runway development have shown that financial risk exposures due to environmental issues are from time- and cost-overruns because of delays caused by environmental lobbyists and interest groups. This is apart from costs associated with compliance with environmental laws and regulations for prevention, restoration and compensation.

3 Overview of PFI

The Private Finance Initiative (PFI) is, currently, the Government's main innovative instrument for the delivery of public services in the UK. It presents the public sector with the opportunity to procure services, or buildings and infrastructure, while leaving the risks of asset and infrastructure ownership and maintenance with the private sector.

The two fundamental requirements of the PFI are that the public sector must secure value for money; and there must an appropriate transfer of risk to the private sector.

A major element of the PFI is that the consortium responsible for the provision of the PFI can adopt an innovative design, construction, and operation approach. For example Design, Build, Finance and Operate (DBFO) and Build, Operate and Transfer (BOT) leading to fundamental improvements in quality, cost and time of delivery of public infrastructure [17]

Principal risks relevant to PFI schemes which are expected to be transferred to the private sector are design and construction risk (with particular reference to cost and time); commissioning and operating risk (including maintenance); demand for volume/usage risk; residual value risk; technology/obsolescence risk; and regulation and legislation risk.

Environmental risk is part of regulation and legislation principal risk. Government bodies, project lenders, investors and developers all have a greater degree of corporate responsibility than before, for appropriate consideration to environmental matters and compliance with environmental legislation and guidelines when considering major project development. Under PFI it is expected that the consortium will comply with all environmental laws, directives and regulations. Such directives will include those relating to air pollution control, water pollution programme, waste management, etc.

The EC June 1985 [18] directive on environmental impact assessment, for example, requires an evaluation of potential environmental 'impacts of proposed projects. The Directive requires an environmental assessment of major public and private projects which takes into consideration the nature, size, and location of the proposed project [3].

Under the PFI procurement method, compliance with EC directives, for example, becomes the responsibility of the private sector responsible for providing the public sector services. It becomes the responsibility of the PFI consortia to consult with the local community and organisations such as "Friends of the Earth" at the feasibility stage of the project to accommodate their views or negotiate the process in order to avoid project delays, additional costs and bad publicity. As part of the PFI deal, financial institutions (project lenders) are expected to conduct environmental assessments of commercial transactions in order to control risk exposure from environmental liability.

In summary, the PFI places more responsibility on the private sector to carry additional risks including environmental risk associated with public sector schemes.

4 Innovation and Sustainable Development through PFI procurement

Sustainable development is a major concern to the world and formed the basic theme of the report 'Our Common Future' produced by Brundtland commission for the United Nations. [19]. The report described sustainable development as 'development that meets the needs of the present without compromising the ability of the future generations to meet their own needs'. The report further recognised that the environment is where we live and development is what we all do in attempting to improve our lot within that abode, and as a result the two are inseparable.

Sustainable development in construction procurement is about more concern for environmental issues at various levels of decision making within the construction process including budgeting, design, construction, operation and maintenance.

Traditionally, the risk associated with environment issues for public sector projects is borne by the government.

Under PFI, the public sector is expected to produce a business case, or proposal for the scheme. This specifies both the functional and performance or output requirements for the scheme. The private sector then transforms this to a service design which should meet the performance requirements specified by the client. The consortium is expected to operate, effect repairs to and maintain, the asset throughout the contract period to an agreed quality standard and ensure continuity and quality of service of the asset.

Because the PFI consortium takes control of the design, construction, operating and financing of the scheme, there is opportunity to introduce innovation that will ensure sustainability of the service provision. The consortium, at the design stage, has the opportunity to assess the environmental quality of the scheme and the consequent potential for reducing environmental damage by improving the design.

The PFI procurement method provides the consortium with a greater opportunity to assess the environmental quality of a scheme at the design stage. The overall implication of the environmental assessment at this stage is that the life cycle of the scheme can be considered, including environmental implications and sustainability

5 Environmental Risk Assessment Process

The basic steps involved in environmental risk assessment are risk identification, risk evaluation, risk prevention and loss control, and risk financing and effective monitoring [20], [21].

5.1 Risk identification

This is about identification of the total impact of a project and its effect not only on the environment but also on the local community and the nature conservation interests. A risk matrix could be produced which identifies crucial environmental issues and assesses their potential impact. This may include identification of existing environmental problems about the site and adjoining property through a record search, site inspection and report.

Techniques of risk identification used in processing sectors can be classified into three categories namely: intuitive, inductive and deductive. These techniques are facilitative tools to maximise the opportunity of identifying all the risks in a particular system, facility, or product. Intuitive method includes brainstorming. Inductive methods include checklists; preliminary hazard analysis such as hazard and operability studies (HAZOPS); human error analysis such as failure modes and effects criticality analysis (FMECA) and fault tree analysis. Deductive techniques include hindsight and event tree analysis.

- HAZOPS are structured brainstorming techniques carried out by a multi-disciplinary team of experts, useful for identifying potential hazard in buildings and facilities at all stages of the design and development.
- FMECA is carried out by an individual expert with a thorough understanding of the system using a step by step procedure to identify failure modes or design weaknesses and the criticality of the consequences of failure.

- Fault tree analysis demonstrates an understanding of how the failure could occur in the system and what effect modification might have by looking through all the branches of the system.
- Hindsight is based on learning experiences from techniques of investigation and analysis undertaken in the past.
- Event tree analysis shows the consequences of a particular fault identified from the fault tree analysis resulting in elimination of those paths which lead to the more severe consequences.

5.2 Risk evaluation and quantification process

This is about the generation of quantitative information on the environmental risks associated with schemes. It involves tools and techniques for quantifying potential environmental loss exposures and cost, in the area of environmental compliance, auditing for effective waste reduction and minimisation. Quantification deals with assessing the probability of the failure occurring and the consequences if it does, while evaluation deals with tolerability and acceptability of risks.

Techniques of risk quantification include reliability estimation using reliability block diagrams and network analysis, fault trees, event trees, computer modelling such as Monte Carlo simulation and expert systems. Techniques of risk evaluation include:

- Risk criticality matrices which are based on two by two matrix indicating the various criticality levels. Evaluation exercises are undertaken by noting the relative position on the matrix of the variously identified risks, prioritising and establishing the acceptability threshold, through the ‘as low as reasonably possible’ (ALARP) principle.
- Cost effectiveness is based on budget; the evaluation techniques depend on the lowest risk which can be achieved within the budgetary constraints.
- Cost-benefit analysis evaluation techniques are guided by whether the cost of the risk reduction measure is less than the value of the benefit achieved, in which case the reduction measures should be implemented.

5.3 Risk prevention and loss control

This includes a programme of risk prevention including pollution prevention, risk communication and crisis management (i.e. emergency planning e.g. chemical spillage).

5.4 Risk financing and effective monitoring

This involves an evaluation of an array of risk transfer and risk retention methods for safeguarding corporate income through commercial insurance, risk retention groups and captive insurance companies [5].

6 Environmental risk ranking and risk analysis techniques in construction

Risk strategy is governed by the number of different types of risk an organisation considers, the likelihood of their occurrence, and the likely severity of their impact [22]. Obviously, PFI schemes have many risks, including environmental, for the consideration of the consortium. Although the likelihood of occurrence of environmental risk may be low, the likely severity of impact is usually high (see section 2).

Table 1 based on the research survey of 42 respondents (government departments, contractors and financial institutions) that are involved in PFI Projects [23] shows that environmental risks were ranked 16th out of the 26 listed risk factors that the public sector requires to significantly transfer to the private sector.

Table 1: Respondents ranking of PFI risk factors

RISKS	Respondents			
	All	**Lenders**	**Contractors**	**Clients**
Design Risk	1	10	1	5
Construction Cost Risk	2	6	2	6
Performance Risk	3	8	4	2
Risk of Delay	4	7	7	3
Risk of Cost Overrun	5	2	3	9
Commissioning Risk	6	5	17	1
Volume Risk	7	3	8	10
Operating / Maintenance Cost	8	13	9	4
Payment Risk	9	1	10	14
Tendering Cost Risk	10	9	6	17
Contractual Risk	11	15	5	11
Legal Risk	12	12	11	19
Market Risk	13	11	14	16
Residual Value Risk	14	14	16	12
Planning Risk	15	19	13	18
Environmental Risk	16	23	15	8
Safety Risk	17	20	21	7
Financial Risk	18	18	12	22
Credit Risk	19	4	25	24
Possible change in government	20	16	20	20
Project Life Risk	21	22	24	15
Changes in European legislation	22	26	19	13
Development Risk	23	24	18	21
Bankers Risk	24	17	23	26
Debt Risk	25	21	22	25
Land Purchase Risk	26	25	26	23

However, the risk factor is important to the clients and this has been ranked 8th. The high ranking of risk factor by the government department would suggest that it is important that the risk is transferred to the private sector in view of the need to comply with both the EC regulations and directives and the OECD on environmental protection. Recent cases of DBFO schemes delayed due to protests by ‘anti-roads activists’ and ‘Friends of the Earth’ include the M3 Motorway extension (Newbury bypass scheme) [24]. The demonstration caused cost and time overruns to the public sector and tended to reinforce the need for the risk involved to be transferred to the private sector.

Although contractors and project lenders have ranked environmental risk 15th and 23rd respectively, this may tend to suggest that either they do not wish the risk to be transferred to the private sector, or they underestimate it, or they do not feel that they have more responsibility for environmental risk under PFI procurement, perhaps even they believe they are not capable of mitigating this risk or they lack expertise in risk analysis techniques required in dealing with environmental risks etc.

Table 2, based on a research survey of UK contractors [25], shows a lack of expertise in generic risk analysis techniques. In the survey the respondents were asked to identify the techniques or methods of risk analysis they are familiar with, and ones that are being used by their firms for project risk analysis and management. The report shows that the use of risk analysis techniques by the responding firms is generally low in construction projects with the exception of Intuition/checklist. This method of risk analysis has been criticised because although it is possible to make a long list that is reasonably comprehensive, this approach gives little confidence that all risks have been identified [26]. The table also shows that most of the respondents are familiar with sensitivity analysis technique but the knowledge of advanced methods such as decision trees analysis, Monte Carlo simulation and subjective probability is low.

Table 2: Usage of techniques of Risk analysis (by per cent of the respondents)

Risk analysis methods	Respondent familiar	Use within Organisation
Risk premium	27	33
Risk adjusted discount rate	17	7
Subjective probability	17	23
Decision analysis		
Algorithms	3	0
Mean end analysis	7	0
Decision trees	27	13
Bayesian theory	7	0
Sensitivity analysis	53	53
Monte Carlo simulation	20	3
Stochastic dominance	0	0
Caspar	0	0
Intuition/checklist	77	77

The results show that many risk assessment methods such as Monte Carlo simulation (designed to provide quantitative estimates of the risk associated with a proposed action) are not used in main stream construction activities talk less of environmental risk assessment. These techniques are increasingly routine, for instance, in both the insurance and chemical industries, and are being frequently used by energy production and electric utility firms.

Overall the result of ranking environmental risk and risk analysis techniques in the industry suggested that the construction industry's risk management philosophy is fatalistic rather than holistic. According to Smallman [22] companies or industries following the holistic paradigm will generally tend to consider all types of risk facing them regardless of the likelihood and severity. Such companies or industries will also tend towards an overall policy of avoiding risks. Whereas the characteristics of fatalistic or reactive approach are found in the construction industry i.e. organisations rely largely on risk retention (accepting loss) and risk transfer (hoping that some other institution will bear the loss). The 'holistic risk management' or pro-active approach demand that risk must be avoided, prevented and reduced through strategic management including organisational learning, proven qualitative and quantitative risk assessments and risk forecasting [22].

7 Conclusion

The current responsibility of the private sector under the PFI demands that they review carefully their current practices in facility design, construction, operations and maintenance. Research to date shows that construction contractors have not taken seriously the demands of environmental laws and regulations on their business activities. There is no doubt that environmental matters constitute financial threat to construction business activities. Traditional procurement practices show that the responsibility for environmental issues could be transferred to the client. The current innovative procurement methods such as the Private Finance Initiative (e.g. DBFO, BOO, BOOT etc.) demand that the construction industry absorbs more risks, including those associated with the environment, as part of their business risk.

The construction industry, generally, shows some characteristics of the fatalistic approach to risk management with tendencies towards risk retention and transfer of construction business risk, including environmental risk, rather than proactive or holistic risk management that is associated with strategies leading to risk avoidance and loss control (risk prevention and limitation).

Although the construction industry has not shown enough competence in the use of risk analysis and management tools, techniques and methods, this paper identifies some proven techniques of environmental risk assessment that are in use in the processing industry sector that the construction industry can learn from. Also it is hoped that the framework for environmental risk assessment presented in this paper will stimulate both theoretical and empirical research that will strengthen our understanding of environmental issues in construction.

References

1. Porter, M.E. and van der Linda (1995) Green and competitive: ending the stalemate. *Harvard Business Review,* Vol. 73, No. 5, pp. 120-34.
2. Shrivastava, P. (1995) Environmental technologies and competitive advantage. *Strategic Management Journal,* Vol. 16, Special Issue, pp. 183-200.
3. Campbell, L.B. International Environmental Risk Management. *Environmental Risk Assessment, A Desk Reference,* Rothenberg E.B.and Telego D.J. (eds.), RTM Communications Inc. pp. 359-398.
4. Wilson, A.R. (199 1) Environmental risk: Identification and Management, Lewis Publishers Inc., USA
5. Root, F R (1988) Environmental risks and the bargaining power of multinational corporations, *The International Trade Journal*, Vol. 3, No. 1, pp. 111-124.
6. Ullman, H (1986) Insuring environmental risks. *Insuring for Environmental Risks,* Davidson K and Pfennigstorf (eds.), Witherby & Co Ltd, London, pp. 3-9.
7. Pasquire C L (1997) The implications of environmental issues on construction procurement. *Proceedings CIB W92 - Procurement - a key to Innovation,* Davidson C H and Abdel Meguid T A (eds.) pp. 603-613

8. Johnson, S. and Corcelle, G. (1989) *The environmental policy of the European Communities,* Graham and Trotman, London
9. Caddy, J (1997) Hollow harmonisation? Closing the implementation gap in Central European environmental policy. *European Environment,* Vol. 7, No. 3, pp. 73-79.
10. Commission of the European Committees (CEC) (1992) *Towards sustainability: a European Community Programme of Policy and Action in Relation to the Environment and Sustainable Development,* CEC, Brussels.
11. CIRIA (1994) *Environmental handbook for building and civil engineering projects, Construction phase.* Special Publication 98.
12. OECD (1996) *Environmental performance in OECD Countries,* Organisation for Economic Co-operation and Development, France.
13. Lizieri C., Palmer S., Charlton M., Wilson, C. and Finlay L. (1996) Valuation methodology and environmental legislation: a study of the UK commercial property market. *The RICS Research Paper Series,* Vol. 2, No. 3, RICS, London.
14. Baker A H (1985) Environmental risk management. *Journal of Accountancy,* October, pp. 159-163.
15. Zuber G R and Berry C G (1992) Assessing environmental risk. *Journal of Accountancy,* March, pp. 43-48
16. Brodecki, Z (1986) Claims for the benefit of the environment in the United State: A foreign perspective. *Insuring for Environmental Risks,* Davidson K and Pfennigstorf (eds.), Witherby & Co Ltd, London, pp. 49-64.
17. Miller J B (1997) Procurement strategies which encourage innovation: The fundamental elements of Sustainable public infrastructure systems. *Proceedings CIB W92 - Procurement - a key to Innovation,* Davidson C H and Abdel Meguid T A (eds.) pp. 443-452.
18. European Community (1985) *Council Directive 85/337/eec on the assessment of the effects of certain public and private projects on the environment,* Official Journal, L175/40
19. World Commission on Environment and Development (1987) *Our Common Future.* Oxford University Press, Oxford.
20. Rothenberg, E B and Telego D J (1991) *Environmental Risk Assessment, A Desk Reference,* RTM Communications, Inc. pp. l-3
21. Frosdick, S. (1997) The techniques of risk analysis are insufficient in themselves. *Disaster Prevention and Management: An International Journal,* Vol. 6, No. 3, pp. 165-177.
22. Smallman, C. (1996) Risk and organisational behaviour; a research model. Disaster Prevention and Management, Vol. 5, No. 2, pp. 12-26.
23. Akintoye A, Taylor, C and Fitzgerald (1997) Risk analysis and management of Private Finance Initiative projects. *Engineering, Construction and Architectural Management* (in print)
24. Contract Journal Road Supplement (1996) What future for direct action protest. Contract Journal, June, pp. 11
25. Akintoye A and MacLeod M J (1997) Risk analysis and management in construction. *International Journal of Project Management,* Vol. 15, No. 1, pp. 31-38.
26. Jamieson, R. and Low, G.(1990) Local area network operations: a security control and audit perspective. *Journal of Information Technology,* Vol. 5 pp. 63-72

Environmental Concerns V's Commercial Reality - Who Really Pays for Construction Waste?

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Abstract

The procurement team's approach to construction, and more importantly individual participants' approach, will affect the contribution made to the built environment: buildings not only use scares resources in their construction but also generate a great deal of waste during the construction phase, waste which has to be disposed of and could be reduced considerably. This paper presents a view from an architect (client briefing and design phase) and a construction manager (building phase) of the way in which waste is generated and subsequently disposed of during a building project. Through a number of case studies the authors address the balance between financial and environmental concerns during procurement. The case studies, along with the authors' individual views help to illustrate the difference in culture between the design and construction phases in a buildings life. Although the case studies were not linked, there was a clear emphasis on cost, with environmentally responsible behavior closely linked to cost benefit. It was also evident that designers were looking to the site for improvements in waste control (outside of their control) and site agents were looking toward the designers for more to be done at the design stage (outside their control).

The concept of individual responsibility within the temporary procurement team is an area for further investigation and research. Furthermore, it appeared that one of the main barriers to reducing waste on site was one of existing values and a lack of effective communication between parties. Control of construction waste should be seen as a continuing process at all stages in the life of a building, but the wide variety of participants, all with differing values, goals and responsibilities, such control is always going to be difficult. It is the social and structural issues that need to be addressed rather than issues of a technical nature, combined with communication between designer and builder - in short a re-assessment of building procurement for an environmentally responsible age.

Keywords; Communication; Individual responsibility; Land. fill tax; Temporary procurement networks; Waste management.

Introduction

Recent legislation, originating from a European Commission Directive requires the health, safety and welfare of a structure to be considered and costed (in terms of adequate resources) for the entire life of that structure. It is suggested, as a minimum, that the same consideration needs to be given to the waste disposal, and embodied energies of a building at feasibility stage so that the impact of building can be reduced. Although landfill tax increases, of £ 2 per tonne on inert material and £ 7 per tonne on biodegradable material, may help to reduce the amount of landfill and may lead to an increase in recycling of building materials, once a building is built both the volume and type of material is fixed within the structure until demolition and disposal. The disposal of the building is limited to what can be done with the materials and material types which were selected at design stage. Certain materials or composite materials are less easy to recycle or dispose of than others and paradoxically recycling of materials may demand more energy, possibly causing greater harm to the environment than reuse would justify. Consideration needs to be given to the possible reuse of the materials and the amount of waste in the event of demolition at the design stage. Thus developers and designers needs to consider production and demolition, as well as the building in use, when assessing its impact on the environment at an early stage in the procurement process if real reductions in building waste are to be achieved.

Competitive construction and the environment

The main argument for reducing and recycling waste has to be related to cost, since waste costs money [1]. Construction contractors have to balance cost against the environment. In a recent survey [2] when contractors were asked if they would use green products or materials, a significant number of the contractors added a note that "the cost would have to be equal or the client would have to be willing to accept the additional cost in using the eco-label products". A construction company will not stay buoyant unless it wins competitive tenders. The majority of the clients are in the business of selecting the most competitive contractors; balancing cost against the quality of company. Without doubt the image of a quality construction company may be built on an infrastructure of previous quality construction products, good safety records and possibly an environmental awareness. However, what is commercially the most competitive product or process may not be the most beneficial to the environment; there is an imbalance, it could be financially incorrect to select the cheapest product when the environmental costs are carried by others. Financial costs to the country, directly associated with environmentally unfriendly materials include;

- control and disposal of waste, landfill sites, incinerators.
- control of pollution to the ecological system correction measure where the environment is damaged.
- control of emissions, atmospheric pollution.
- research funded to investigate environmental problems caused by construction waste.

- energy costs

When products and processes eventually harm our environment so much that attempts are made to rectify the situation, the majority of the costs are picked up by tax payers, both now and in the future. What is happening is that those cheaper more cost effective processes and products, which do not consider waste management, are costing more. It is fundamentally wrong that a material is used from the other side of the globe, which uses more energy and packaging in transportation, when a comparable material is available in this country - there are clearly problems with the global economy. The cost of disposing discarded packaging is borne by individual countries, whilst the wasted energy and emissions affects the entire planet. In a survey [2] specifically targeted at developers in the construction industry, cost always took priority over any environmental issue. When considering factors effecting product selection, the recycling potential of the product, 'green factors' were given less consideration than cost, durability, whether the product had a British Standard, the appearance, previous use of the product and maintenance costs. Regardless of any environmental conscious image which clients, architects and developers wish to portray it is apparent that little effort is devoted to reducing the impact of the construction industry on the environment on an individual level. Designers, developers and contractors must be forced (encouragement is not enough) to develop buildings which are recyclable.

An architect's view

The adoption of environmentally responsible ideas and practices in building an extremely complex issue because of the extensive networks that develop for any one project [3]. These networks are at best temporary, in that they form for one particular project and dissipate when the building is completed. Since every building differs from the one that preceded it in some way (different site topography, different client, different consultants etc.) any new networks that form are likely to be different in their composition and goals to the one that went before. Therefore, the transfer of experience from one project to the next may not necessarily be possible or indeed applicable.

Before looking at the specific issue of site waste, it is necessary to look at the participants in the design and construction process, the nodes in the network. If we start with a very simple model, comprising a client, an architect and a general contractor and look at their potential contribution to the building process;

The client, whether an individual or a large corporate body, will affect the building programme by the amount of money and time available for a specific project. The aspirations of the client body and those of the individual, the client's representative, will also influence the process, thus clients have an important role to play in the adoption of environmentally responsible practices. One of the main contributions is the proposed design life of a building: from experience gained in an architect's practice this is one area where architects constantly strive to select products that are durable and have a long life in service but an area where the majority of clients require a building which will have a short life. For example, many buildings are designed with service lives of as little as 15 years, after which time they will be demolished and replaced simply because the client will profit financially from such a development practice. One (extreme) example of this was a client who asked for a building to be designed for a five year service life, after which time it was to be demolished and the site redeveloped, however, there was no possibility of designing for dis-assembly because of time and cost constraints imposed by the client.

As designers of the building and selectors of building products which make up its assembly, architects have a significant role to play in the adoption of sustainable practices. However, they are constrained by clients' aspirations and may often be limited in their action by constraints imposed by the client's pre-contract team and constraints arising from project constraints, discussed below.

As the actual builder, contractors are constrained by the designers instructions, the builder's environmentally responsible practices are limited to control and management of on site systems ensuring that wastes and emissions are kept at a minimum. Though discourse and feedback a contractor could aid or influence design changes on the current and future projects, however, such an exchange of information will be dependent on the architects and clients attitude towards contractor involvement in design issues. The contractor still has a role to play in the control of waste, indeed it is suggested that good site management can significantly reduce waste and control and reduce associated costs.

A construction manager's view

Presently a small percentage of the material is recycled: in 1994 it was claimed that 80% of construction waste ends up on landfill sites [4]. Even though this has been reduced by 43%, through the impact of landfill tax, it is suggested that much of the waste is diverted to unregulated activities such as golf course landscaping and land spreading on farms [5], however the burden of construction waste still rests with landfill sites. Although tax on waste bound for landfill sites has increased, it has not altered the fact that building are increasingly being built out of less disposable and recyclable materials at an increasing rate. The size of buildings and the speed of construction is increasing posing a massive problem for waste management, the amount of waste generated is obviously linked to the size of the structure, furthermore the new buildings have shorter life spans than their predecessor. In many cases "buildings are designed with obsolescence in mind", demolished after 25 years use [6]. The harm to the environment is at least three fold, demand on resources; emissions during building, demolition and recycling; and the impact of the un-recycleable disposable element of the structure.

Even though the industry both creates and fills voids, the situation. is not in equilibrium; waste generated by society is greater than the voids created by mining [7]. To remove the impact on the environment the industry should reduce its demand on raw material, through recycling and reuse, The burden of the extra tax on waste of the building bound for demolition is placed with the developer of the new building project. Although the building will incorporate the costs of removing previous developments, it is argued that the design of the new structures does not place sufficient regard to demolition, dismantling or assessing the eventual disposal of the structure, especially when life spans of buildings are being reduced. The responsibility for waste and the impact on the environment concerns every stakeholder in the building process [S]. Solutions to reducing waste must be at the forefront of all; clients, developers, designers, contractors, manufacturers and suppliers when designing their process or product. In research carried out on material control and waste on building sites [8], it was found that;

- Considerable waste of resources occurs when the project information is inadequate when work has commenced.
- Materials handled by plant not designed to handle the product leads to damage and waste.
- Inadequate or incorrect packaging leads to damage when handling.
- Untrained operative using incorrect procedures leading to damage.
- Inadequate stacking or insufficient storage space was a principal reason for waste.
- Excessive cutting of materials due to designers not taking account of practical sizes
- Material quality of the product delivered varied from specification leading to rejection and waste.
- Lack of supervision and responsibility led to misuse and damage of materials.

The research identifies many faults of material control leading to waste which could easily be rectified with practical material management systems.

(The following case studies were carried out before recent changes to financial levies on waste skips).

Case study 1

The following case study is based on an architectural firm's attempts to introduce a number of environmentally responsible practices, over a four year period. It is important to note here that the firm made no claim to be 'green', it was (and still is) a firm orientated towards the commercial market, with an excellent reputation for service and delivery. However, the firm attempted to implement better practices on every project, an aim not always achieved. There are two related issues explored here, namely the selection of building products and the control of waste on building sites.

First, the architects aimed to detail each building in excess of the then current thermal regulations. This added additional initial cost to the building, but some relatively simple arithmetic indicated that this was soon recovered through reduced heating costs, thus saving energy (and money) in the long run. Whilst some clients, usually owner operators, were relatively happy with this approach, clients who were developing a site for commercial reasons and who were going to sell the building on completion were not interested in the long term cost savings and insisted on the building being designed to the minimum standards required under the current Building Regulations to keep initial costs down: clearly not all clients are orientated towards a sustainable future.

Second was a desire to cut down on the amount of waste generated on building sites during the course of construction. This came about through a desire to reduce costs, through reducing waste material on site, paid for and not used, and also the cost of disposing of it to appropriate tips. Thus waste material attracted two costs, both of which, hypothetically, could be reduced, but which in practice is much harder to control. The cynic here would argue that it is not in the contractors interest to reduce waste because the firm makes a profit on all material purchased and makes a profit on transporting waste material to the tip. Others may argue that many contractors are simply unable/or unwilling to do anything about waste generated on site, simply because of well established (bad) practices, whilst others may well argue that it is in the hands of the architects. Such control requires additional time, for monitoring and supervision, both on behalf of the architect's office and the contractor. From an architect's perspective it is difficult to charge the client for this time, time which is not always available given programming pressures for fast completion.

The architectural practice were fortunate in having a small number of repeat clients who were concerned with environmental issues and did want to make a contribution, which helped to balance the clients who did not. The practice, with the backing of the client, undertook a small pilot scheme where an attempt was made to reduce waste generated on site. The first task was to f-e-assess the design of the building. Since the building had been refined over a number of years, with a view to reducing costs and improving design quality, the assessment found that little could be done. The issue of prefabrication off site was investigated, but since the buildings were all different to some respect (largely to suit site constraints and local planning requirements) this option was ruled out. Therefore material control at design stage had been considered. Next was to look at what happened on the site. Since a small number of contractors constantly won the competitive tender for the building there was some consistency here and two of the contractors were monitored over five projects each. The monitoring was very simple (since there was no time available to do anything more sophisticated) and comprised a visual inspection of the site tidiness by the clerk of works on his daily visits and a check of the number of full skips sent to tips, from documentation submitted by the contractor: the clerk of works also attempted to make a note of the contents in each skip from a visual inspection. At each pre-contract meeting the architects asked the contractors to pay special attention to site tidiness and to try and limit the amount of waste generated, to which they were happy to agree.

Once building work started on site things were not so simple. Of the ten sites monitored, (five for each contractor) each site had a different site manager and each employed different sub-contractors to carry out certain elements of the work. What the study found was that site tidiness and the number of skips sent to the tip were linked, the tidier the site the less waste, but more importantly both issues were associated with the personal characteristics of the site manager (regardless of which company he was working for). Clearly, the pressure to get the building completed on time and to a specified quality overrode any concerns about waste or site tidiness - with each building site monitored, as the programme neared its completion and the pressure to complete the building mounted, the site became increasingly untidy and the skips filled all the quicker. From a visual inspection the majority of materials thrown into the skip were re-useable, such as short lengths of timber, chipped facing bricks etc., whilst a lot of waste was generated from the packaging used to protect building materials whilst in transit from the factory to the site. Despite requests from the clerk of works and also the architects at monthly site meetings to address this issue the number of skips going to tips did not reduce significantly.

In analyzing this small study, a couple of important issues are evident. First, the values of the contractor (and the sub-contractors) are different to those of the architect and client. Second, control of waste on site is the contractor's responsibility (not the architect's) and therefore, if for whatever reason, the site manager does not concern himself with such issues there will be no reduction in waste. In the studies reported above it was clear that contractors had little experience, or desire, to control or even measure waste on site.

Case study 2

The following observations were made over a two year period. The case studies examine practices and procedures associated with the handling of skip waste on four different sites The significance of waste to the site agent is cost, waste costs money. The studies show that cost orientated site agents can save money by controlling waste.

The first site agent observed held what could be considered an authoritarian approach to site control, if waste increased beyond what was considered his acceptable waste limits he came down hard on the subcontractors threatening to withhold moneys for excessive waste. Subcontractors were instructed to protect their materials, where their materials were damaged the site agent refused to be involved. Subcontractors became much more vigilant, possibly even aggressive towards others who may have damaged their goods. Site organization and logistical arrangements were adhoc and as such the possibility of damaging materials was high, (profiled metal cladding panels were damaged in bulk quantity by site plant on one site, although this material was sent to be recycled, wasted energy would be involved in the process). Very few skips (in comparison to the other studies) left this site, all operatives and staff on site were made fully aware of the cost of waste. Due to the authoritarian style of management, on all issues, a low moral on the site was observed. Subcontractors did not cooperate, the majority of personnel were very defensive, however protection and personal responsibility for materials was clearly apparent.

Two of the other site agents also attached a high priority to the control of what materials went into skips. Both of these site agents seemed to be more aware of what could be sold or reused. The site seemed possibly more organized, good housekeeping seemed to hold a higher priority, and as such slightly more material was removed by skips: these contractors were operating profitable sites.

The fourth site agent although well qualified and experienced was not running an organized controlled site. Little emphasis was placed on waste control. Multiple skips were removed daily, the site agent repeatedly talked about good housekeeping, although the site was rarely clean, even though one operative had a full time position cleaning the site. For the operative cleaning, it was easier for him to clean what could be reused, for example, it is easier to fill a wheelbarrow with off cuts of timber rather than picking up bricks encased in concrete and mortar. Many of the 'labour only' subcontractors seemed to have as much material as they wished, selecting only the best and disposing of the rest. Poor quality work by subcontractors was allowed to get to an advanced stage of construction before work was condemned and pulled down leading to high quantities of waste. The site agent was not operating a profitable site. It is inevitable that any site agent adopting wasteful processes are placing themselves and their companies in a risky position because of the cost implications.

These limited observations identified how individuals were dealing with waste costs within their sites. Clearly site agents who are in financial control undertake waste management seriously. However, if further advances are to be made to reduce site waste, architects need to be more aware of process which create waste during the construction phases and those which are less wasteful. For example, concurrent engineering operated by other industries and now emerging in the construction industry [9] should engage in environmental assessments, coordinating efforts of both designers and contractors.

Conclusion - A way forward

The case studies, along with the authors' individual views help to illustrate the difference in culture between the design and construction phases in a buildings life. Although the case studies were not linked, there was a clear emphasis on cost, with environmentally responsible behavior closely linked to cost benefit. It was also evident that designers were looking to the site for improvements in waste control (outside of their control) and site agents were looking toward the designers for more to be done at the design stage (outside their control). The concept of individual responsibility within the temporary procurement team is an area for further investigation and research. Furthermore, it appeared that one of the main barriers to reducing waste on site was one of existing values and a lack of effective communication between parties.

Control of construction waste should be seen as a continuing process at all stages in the life of a building, but the wide variety of participants, all with differing values, goals and responsibilities, such control is always going to be difficult. It is the social and structural issues that need to be addressed rather than issues of a technical nature, combined with communication between designer and builder - in short a re-assessment of building procurement for an environmentally responsible age.

References

1. Peng, C. Scorpio, D.E, and Kibert, C.J. (1997) 'Strategies for Successful Construction and Demolition Waste Recycling Operations'. in Construction *Management and Economics,* **15,** pp 49-58.
2. Geraghty, P. (1997) *Environmental Auditing and the Development Industry,* Construction Paper, 73, (ed. P. Harlow). CIOB, Englemere.
3. Emmitt, S. (1997) 'The Diffusion of Environmentally Responsible Ideas and Practices' in *Evolving Environmental Ideals - Changing Ways of Life, Values and Design Practices* (ed. Madi Gray), Royal Institute of Technology, Stockholm. 41-49.
4. Friedman, A. and Cammalleri, V. (1994) 'Reducing- Energy, Resources and Construction Waste Through Effective Residential Unit Design. ' *Building Research and Information,* 22: 1, pp 103 - 108
5. Reeds, J. (1997) 'No Time to Waste', in *Construction Manager,.* **3**:5, pp.19-21, June
6. Edwards, D.J., Harris, P.T. and Holt, G.D. (1996) 'The Greenhouse Effect; Impact upon and the Role to be Played by Construction', *Building Research and Information,* **24**:2, pp.97-103
7. Read, A.D, Phillips, P. and Robinson. (1997) 'Landfill as a Future Waste Management Option in England: The View of the Landfill Operators', in *Resources, Conservation and Recycling* 20, pp. 183-205.
8. Enshassi. A, (1996) 'Material Control and Waste on Building Sites', *Building Research and Information,* 24: 1, pp3 1-34.
9. Anumba, C.J. and Evbuomwan, F.O. (1997) 'Concurrent Engineering in Design-Build Projects', *in Construction Management and Economics. 15,* pp 271-28 1.

The Adjudication of Construction Disputes - New Dawn or False Hope?

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Abstract: The UK Construction industry appears at times conflict driven. Claims based on time and money abound. Contractors do not look for 'win-win' solutions and use their lawyers to reach the position they desire through litigation or arbitration. Arbitration, at least in England, has come to resemble litigation with full use of lawyers, the legal rules of discovery and evidence and lengthy and expensive oral hearings. Sir Michael Latham was commissioned to review the practices of the UK construction industry and made a number of recommendations - greater partnering, a departure from the 'lowest tender wins' mentality, less adversarialism in dispute resolution. For Sir Michael, dispute resolution should principally be via adjudication (a term he never defined) and should be used regularly through the course of a project to deal with problems as and when they arose to prevent them becoming festering sores. The UK government enthusiastically embraced adjudication and rushed through hasty and, to some minds, ill thought out legislation. This paper considers the background to statutory adjudication, identifies what adjudication is and explores some of the merits and defects inherent in such a system. Adjudicative decisions must be interlocutory (although the parties may treat them as fmal and binding) not to offend against English arbitral law. Enforcement of adjudicator decisions may be difficult because of the wording of English standard form construction contracts and the provisions of the Arbitration Act 1996. How successful will be adjudication be? With little empirical data, the jury will remain out.

Key words: adjudication, arbitration, Arbitration Act 1996, Conflict, decision, enforcement, final and binding, Housing Grants, Construction Regeneration Act 1996, litigation, natural justice, Sir Michael Latham

1 **Why litigation and arbitration are failing**

A former Chief Justice of the United States of America, the late Warren Burger, once said:

> "The obligation of our profession is.. . to serve as healers of human conflict. To fulfil our traditional obligation means that we should provide mechanisms that can produce an acceptable result in the shortest possible time, with the least possible expense and with the minimum of stress on the participants. That is what justice is all about. "[1]

Leaving to one side the possibly conflicting emotions of those involved in the dispute resolution business, where certain lawyers need to question the value of a "litigation client who is not litigating" and thereby doing his 'duty' in creating billable hours, no sensible person could dissent from Warren Burger's comments. Dispute resolution is a service industry and must recognise client needs. Clients who believe they can abdicate their responsibility for decision making by passing a 'problem' to their lawyers have a rude shock when witness statements need to be produced and a court hearing beckons. Only then do they 'reality test' with the result the litigation implodes and the cost in terms of management time and money either disregarded or explained away. The need for client centred dispute resolution has been taken up by many leading members of the judiciary and was a cornerstone of Lord Woolf's interim and final reviews of civil litigation[2], Access ***to Justice.*** Another very senior judge, the former Lord Chief Justice, the late Lord Taylor, rightly said in identifying the obligation of the legal profession to be responsible in plying its trade:

> "A trial is not a game. The role of a judge should not be restricted to that of an umpire sitting well above the play, intervening only to restrain intemperate language and racket throwing. "[3]

Lord Taylor's remark echoed earlier words of Warren Burger who on one occasion said:

> "Trials by the adversarial contest must in time go the way of ancient trial by battle and blood" [4].

1.1 **Criticism of Litigation**

Increasingly, litigation, the legal process and the ways of lawyers and expert witnesses have attracted a very poor press. Particularly in the United States lawyers are the butt of savage jokes which emphasise their reputed avarice and self interest[5]. Even in the United Kingdom, when the City law firm, Herbert Smith, surveyed the top ***400*** companies in ***The Times Top** 1000* for their views on litigation the lawyers found widespread criticism of the length, complexity and cost of civil justice:

> "A substantial majority (70%) suggested the whole system takes too long, whilst almost ***40*** % suggested that the costs of litigation are far too high. "[6]

Companies apparently support a shift away from oral advocacy in civil trials and a greater emphasis on written submissions. They want judges, not the parties to the dispute, to control the pace of proceedings and to determine how long cases should take. More than ***60%*** of the firms questioned favoured a paper trial instead of one based on oral argument and evidence; and a substantial majority wanted control of the timetable of cases given to a ***procedural*** judge. On the face of it, this appeared to equate with a more inquisitorial approach rather than the painstaking, lengthy and costly Anglo-American example of testing evidence through an adversarial model with lawyers caught in the role of medieval knights in a joust.

Over the years various "captains of industry" have criticised the legal process. For instance, Ian Dixon, Chairman of Wilmott Dixon and the then Chairman of the Construction Industry Council, was quoted on one occasion as saying:

> "You can't win if you go to court. The high legal costs are part of it. Litigation is long and repetitive. The legal system is abysmal and inefficient. "[7]

Such stated dissatisfaction with litigation does not explain the continued willingness of UK parties to embrace adversarial methods of dispute resolution.

1.2 **Criticism of Arbitration**

Arbitration, traditionally promoted by its proponents as a no *nonsense* method of dispute resolution, relying more on technical assessment than on the application of judicial nuances, has for a number of years been regarded as legalistic in the United Kingdom unlike in the United States where it is categorised as an ADR method of dispute resolution. In ***Northern Regional Health Authority -v- Derek Crouch Construction Company Limited Sir John*** Donaldson MR stated:

> "Arbitration is usually no more and no less than litigation in the private sector. "[8]

Similarly overseas, the conclusion reached in an Australian research report into claims and disputes in the construction industry, ***Strategies for the Reduction of Claims and Disputes in the Construction Industry - a Research Report*** (various authors) was that:

> "... arbitration has broken down as a cheap and efficient means of resolving construction disputes, albeit that the cause may be the strenuously adversarial manner in which the disputants themselves pursue the arbitral process. "[9]

1.3 **Arbitration Act 1996**

Whether or not the Arbitration Act 1996 will improve the position and rehabilitate arbitration as a cost effective means of resolving commercial disputes in England time will tell.

The Arbitration Act 1996, the purpose of which is to breathe fresh life into arbitration, has had a long period of gestation. The Departmental Advisory Committee (DAC), latterly with governmental involvement, produced two draft Bills, the second of which went out to public consultation in July 1995. The aim was to restate English arbitration law in clear and *user-friendly* language. Some commentators supported the incorporation into English law of the UNCITRAL Model Law as had occurred in Scotland a few years ago. Decisions of the English courts, exercising their supervisory jurisdiction, had caused disquiet amongst foreign parties who chose London for their arbitration. The promoters of new English legislation decided that although the UNCITRAL Model Law had many useful lessons, English law and practice were too well developed by case law precedents to justify the wholesale adoption of the Model Law. The exercise became one of consolidating the Arbitration Acts 1950-1979, modernising their language and inserting apposite features from the Model Law.

Some of the key provisions in the English legislation are found in sections 33, 34 and 48. Under section 33(l)(b):

> "[the tribunal shall] adopt procedures suitable to the circumstances of the particular case, avoiding unnecessary delay or expense, so as to provide a fair means for the resolution of the matters falling to be determined".

Under section 34 the onus is on the tribunal to organise the arbitral reference and a checklist of appropriate considerations is included in sub-section (2). Important amongst these are (c) which attempts to address the English obsession with general discovery in litigation and arbitration and emphasise the point that discoverable documents should be limited to those which are pertinent to the issues in dispute. Further, and a major departure from English practice is the power found in (g) permitting the tribunal to decide "whether and to what extent the tribunal should itself take the initiative in ascertaining the facts and the law". English case law has long debated the power of arbitrators to adopt an inquisitorial approach and until the 1996 Act had given an equivocal response. Finally, the 1996 Act empowers the arbitrator to act as *amiable compositeur*. To what extent English arbitrators will be liberated from convention by the parties and invited to use the section 46(l)(b) powers remains to be seen.

2 The desire for change

The realisation that all was not well with the construction industry led to the Government/industry inspired appointment of Sir Michael **Latham** to review procurement and contractual arrangements in the construction industry. In his final report, *Constructing the Team*[10] he identified adversarial attitudes as a major cause of malaise in the English construction industry. One of the by-products was more expensive construction costs in the United Kingdom (30% higher than in the United States) which he wished to see reduced by the year 2000 (a view greeted with incredulity by the industry)[11]. For Sir Michael there were two responses to the industry's problems: (1) partnering at the front end of projects and (2) adjudication throughout the project to nip problems in the bud and resolve issues when they arose, avoiding unnecessary involvement of lawyers and claims consultants.

3 Adjudication - a new beginning?

Adjudication is not a new concept for English lawyers. It has been an intrinsic, even if peripheral, part of construction sub-contracts since the mid-1970s to review main contractor set offs although it is frequently deleted by main contractors and, because of the wording of sub-contracts forms, has been held not to bite on main contractor claims in abatement.

The definition of adjudication is somewhat vague and the distinction between it and arbitration fuzzy. This is because adjudication (leading to an imposed decision and adversarial, although of a muted variety when compared to arbitration and more particularly litigation) closely resembles arbitration in many respects. It fundamentally differs from arbitration in that the adjudicator's decision is interlocutory and not final. In effect, the adjudicator's decision is binding on the parties if they choose to accept it, or until such time as one of the parties commences legal proceedings or arbitration to determine finally the dispute or the parties, of their own volition, come to their own agreement. Although a contractual mechanism for the resolution of disputes, adjudication is quasi-judicial and subject to intervention by the courts. In England, intervention correlates with the principles of natural justice (ie. giving each party the right to understand the case being made against it, put its own case in its own words and understand the thought processes of the person (a neutral outside the influence of either party) making a decision). The courts are reluctant to lay down hard and fast rules as to what constitutes natural justice. In *Wiseman -v- Borneman*[12], Lord Reid stated:

> "Natural justice requires that the procedure before any tribunal which is acting judicially shall be fair in all the circumstances, and I would be sorry to see this fundamental principle degenerate into hard-and-fast rules".

3.1 Categorising the parties: dispute mechanism

The tension between an adjudicative and an arbitral procedure is sometimes crucial. The English courts will look at the underlying fundamentals of the parties!' arrangements rather than simply be beguiled by their nomenclature; [13]

> "The way in which the reference is described in the agreement to refer is not conclusive as to the character of the proceedings. Thus, even an explicit agreement that a matter be dealt with by arbitration does not mean that the parties intended the proceedings to be the type of arbitration which is the subject of the Arbitration Acts or the common law of arbitration. For example, the use of this word is consistent with any intention to invoke a process which involves a decision by any impartial body, but not one which is binding in law".

The interpretation of particular clauses has been considered in the common law jurisdictions. In ***Sports** Maska **Inc** -v- Zittrer*[14] the Supreme Court of Canada considered that the language used was not definitive and what may be described by the parties as an expert determination may, on objective analysis, be an arbitration. The question was also considered in England[15] where the Official Referee decided that what purported to be an adjudication clause in a management contract derivative was in fact an arbitration clause, given that the result was final and binding.

3.2 Adjudication and arbitration - the interface

A further potential problem adjudication has in England is enforcement of the adjudicator's decision where there is also an arbitration clause in the contract. ***A Cameron Limited** -v- **John** Mowlem &* Co *plc*[16] established that an adjudicator's decision was not equivalent to an arbitrator's award and was not registerable as an arbitral award under the Arbitration Act 1950 (now the Arbitration Act 1996). Typically, at the end of an adjudication, if one party refuses to comply with an adjudicator's decision, the other party will commence court proceedings to enforce the decision. The traditional route has been to seek either summary judgment (which involves a short hearing in which evidence is adduced by way of affidavit, without any witnesses being heard), or an injunction requiring the recalcitrant party to comply with the adjudicator's decision. For example, ***in Drake** & Scull Engineering **Limited** -v- **McLaughlin** & **Harvey** plc*[17] the Official Referee granted an injunction upholding the adjudicator's decision that monies be paid to a trustee stakeholder pending the outcome of an arbitration.

However, if the parties' contract contains an arbitration clause, alongside any adjudication clause, section 9 of the Arbitration Act 1996 would be triggered. This calls for a mandatory stay of any court proceedings brought if an arbitration clause exists in the parties' contract. Thus, existence of the arbitration clause would deprive the court of jurisdiction to decide whether the adjudicator's decision should be enforced (ie. either by summary judgment or by an injunction); the matter would then have to be arbitrated. The English Commercial Court has held itself unable to wriggle out of the mandatory stay[18]. This potential problem can be addressed by providing that the arbitration provisions in the agreement do not apply to enforcement of an interlocutory decision of the adjudicator. The Arbitration Act 1996 may be able to assist with enforcement of an adjudicator's decision. This is because (unless the parties otherwise agree) section 39 permits provisional awards similar to summary judgment or interim payments and section 48(5) allows an arbitrator to grant injunctions. Thus, a claimant having obtained an adjudicator's decision in his favour could immediately commence an arbitration and seek redress from the arbitrator at an interlocutory stage.

3.3 Statutory adjudication in the UK

Following Sir Michael's report[19] the UK government enthusiastically embraced adjudication[20] and legislation was rushed through Parliament to regulate one distinctive sector of the UK economy deemed unable to put its own house in order. Although at the date of preparation of this paper a commencement date for the legislation is still awaited, the UK government has sought to institutionalise adjudication, making it applicable to a wide range of construction contracts for work within England, Scotland and Wales. Subject to the exclusion of certain process plant contracts and domestic building contracts[21] the Act applies to the full range of construction contracts[22]. The HGCRA gives any party to a construction contract the right (but without imposing the obligation) to refer a 'dispute' (which is defined as any difference) to adjudication[23]. This permits the adjudicator to exercise a wide brief extending beyond time and money claims to include a consideration of questions of law, such as: is there a contract? is there a claim in quantum meruit? has there been a repudiatory breach or a wrongful termination of the contract? The term adjudication is not defined in the HGCRA although the HGCRA identifies one of the key features of adjudication by stating "the contract shall provide that the decision of the adjudicator is binding until the dispute is finally determined by legal proceedings, by arbitration (if the contract provides for arbitration or if the parties otherwise agree to arbitration) or by agreement" [24].

Prior to the enactment of the HGCRA in July 1996, the Department of the Environment, which oversees construction in the United Kingdom, stated that statutory adjudication would not resemble arbitration as currently practised there since unlike UK arbitration, adjudication would be "quick and inexpensive" [25]. In order to make adjudication work, the Department of the Environment is putting in place a 'Scheme for Construction Contracts' which will set the benchmark if the parties' contract is deficient in any regard. The first attempt at a Scheme for Construction Contracts[26] was almost universally condemned as a lawyers' charter. This led to a further consultation paper[27]. A draft Scheme for Construction Contracts Regulations was published on the 14th of August 1997 but has been widely criticised.

3.4 Adjudication - success or failure?

Adjudication which trundled on for many years with little or no profile was catapulted into prominence by Sir Michael Latham, leading to the preparation of various sets of adjudication rules[28]. Adjudication will not deal of course with the waste of managerial resources in the construction industry without profound attitudinal changes. It may address genuine claims but will phoney and bloated claims still be taken to the courts and arbitration? How will adjudicators react to contractors who may have worked their claims up over many months and then expect client and adjudicator to respond in a matter of days - is this justice or cynical manipulation of the process? So long as the 'cheapest tender secures the job' mentality persists and contractors artificially suppress their bids to secure work, conflict will inevitably arise when contractors attempt to clawback their position through claims. Adjudication can provide a mechanism for common sense but only to the extent that contractors and clients let it work. Adjudication will not work if one of the parties does not believe in 'truth will out' or reaches for his lawyers in order to thwart the process. Adjudication does have the potential to provide an ideal framework for the sensible resolution of many construction industry disputes and will be facilitated if the English courts demonstrate reluctance to overturn adjudicator decisions. But in the absence currently of empirical data the jury must remain out as regards its efficacy.

REFERENCES

Robert Coulson, ***Professional Mediation of Civil Disputes,*** American Arbitration Association, 1984, at pages 6 - 7.

Final Report to the Lord Chancellor on the Civil Justice System in England and Wales, Lord Woolf, **July 1996,** ***Interim Report to the Lord Chancellor on*** *the Civil* ***Justice System in England and Wales,*** Lord Woolf, June 1995.

Quoted by Lord Alexander of Weedon QC ***in Training Lawyers*** - ***Healers or Hired Guns?*** Child & Co Lecture, 15th March 1995, at page 3.

Quoted by Lord Alexander of Weedon QC, op. cit. at page 5.

By way of example, the writer's favourite anti-lawyer joke goes - Why does New Jersey have all the toxic waste dumps and Washington DC all the lawyers? - New Jersey had first choice.

Times Newspaper, January 1995.

Building, 7th February 1992, at page 9.

[1984] 1 QB 644 at page 70.

Australian Federation of Construction Contractors.

Constructing the Team, Joint Review of Procurement and Contractual Agreements in the United Kingdom Construction Industry, HMSO, July 1994.

op. cit. para 7.48.

[1971] AC 297, HL.

Mustill and Boyd, ***Commercial Arbitration,*** 2nd Edition, 1989 at page 49.

(1988) 1 SCR 564.

Cape Durasteel Limited *-v- Rosser* ***and Russell Building Services Limited (1996) 46*** Con LR 75.

(1990) 52 BTR 24.

(1992) 60 BLR 102.

Halki ***Shipping Corporation*** *-v- Sopex* ***Oils*** [1997] 2 All ER 833.

Latham, op. cit.

Part II Housing Grants, Construction and Regeneration Act 1996 (HGCRA); but note criticism to be found ***in A Plea for Sanity,*** Construction Law Press, King's College, London, December 1997.

Sections 105 and 106 of Housing Grants, Construction and Regeneration Act 1996,

Section 104 of the 1996 Act.

Section 108 of the Housing Grants, Construction and Regeneration Act 1996.

Section 108(3) of the Housing Grants, Construction and Regeneration Act 1996.

Department of the Environment statement accompanying the draft Bill in Parliament. April 1996.

Making the Scheme for Construction Contracts, November 1996.

CEDR Model Rules for Adjudication (still in draft at the date of preparation of this paper); the CIC (Construction Industry Council) Draft Proposals for a Scheme for Construction Contracts, Part One - Adjudication, 18th November 1996; the Official Referees Solicitors Association Procedural Rules for Adjudication 1996 Edition.

Procurement Methods And Contractual Provisions For Sustainability In Construction

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Abstract
The construction process has major environmental impacts and its product relates to, interacts with, and adversely affects, the environment for several years. Various approaches have been proposed to help the industry to contribute to the general effort towards achieving sustainable development. These usually concentrate on the contractor's role, and the construction stage.

This paper considers the possibility of using the procurement approach, and contract provisions to achieve sustainability in construction in Singapore. It discusses the procurement arrangements which are utilised on construction projects in Singapore, as well as the relevant provisions of the two main standard forms of construction contract in use in Singapore. The paper considers areas where the procurement methods and contract forms could be modified to make them able to facilitate the adoption of sustainable construction operations, materials and equipment. It concludes that, as the awareness of potential end-purchasers and users of constructed items in Singapore of issues relating to sustainability increases, developers will have to adopt sustainable construction policies.
Keywords: Sustainability, client's role, procurement methods, contractual provisions, Singapore

1 Introduction

1.1 Construction, the Environment and Sustainability

The effect of construction activities on the environment is now well recognised. These include [1],[2]: (i) competition for land with other activities such as agriculture; (ii) adverse effect on the plots of land which are developed, and their environs, such as changing their ecological characteristics; (iii) consumption of substantial volumes of physical resources, both renewable and non-renewable; (iv) production of substantial volumes of wastes; (v) consumption of large amounts of energy during the processing of materials, the construction process and in the use of constructed items; (vi) contribution to air pollution from the dust and substances, including some toxic ones, which are released during the production and transportation of materials, and in some construction operations; and (vii) disruption of the lives of the people living in the vicinity of the project through traffic diversions, noise pollution and others.

Following the realisation of the relationship between construction and the environment, the need for construction to strive for sustainability in its activities is also understood [3],[2],[4]. Moreover, the nature of sustainable construction and the ways and means to achieve it are also quite established (see, for example, [5,],[6]).

1.2 Pre-eminence of the Construction Client

Construction clients are the prime movers of the work put to the industry. They appoint and pay all the other participants in the projects. Clients have different backgrounds, and dissimilar levels of knowledge of construction. They also have different motivations and interests. These features of the client are reflected in the objectives which they make clear to the project team through the project brief and the resulting production documentation prepared in response to the brief. As clients bear the overall financial risk, all the activities of the other parties involved in the project are, or should be, geared towards attaining the particular objectives of the client. For these reasons, in theory, at least, the client's key interests should drive the project.

Owing to the pre-eminent position of the client on the construction project, several authors (see below) have suggested that the issues relating to the attainment of sustainable construction can only be successfully addressed if clients show interest in, and commitment to, the concept of sustainability. This paper discusses the potential of using the procurement approach, and in particular, the contractual provisions, to achieve sustainable construction in Singapore.

2 Sustainable Construction in Singapore

Singapore wishes to be a "model Environment City" [7]. It has instituted measures to achieve this. These initiatives include [S]: (i) the publication of a ***Green** Plan*: (ii) the introduction of relevant statutes, regulations, codes, incentives, taxes and charges; (iii) the establishment of relevant administrative systems and public education programmes; and (iv) the publication of a document outlining the country's intentions to protect and enhance the built environment in its physical development. Ofori (1993) [8] discusses environmental issues in relation to construction in Singapore.

Studies have shown that whereas a few aspects of sustainable construction are clearly discernible in the operations of construction enterprises in Singapore, the concept of sustainability is not yet a major issue to the nation's construction clients and practitioners [8], [9], [10]. It is not addressed in a systematic or even deliberate manner. The Construction Industry Development Board (CIDB), which manages the continuous improvement of the construction industry in Singapore, and provides the lead on key directions for the industry, has not yet identified sustainable construction as a main consideration, although it realises the importance of environmental issues in construction and has drawn the industry's attention to them [11].

Several authors in Singapore have suggested that progress in the effort to achieve sustainable construction can only be achieved with clients' leadership. Ofori (1992, 1993) [1], [8] outlines the nature and scope of activities relating to the attainment of environmental objectives on construction projects, and highlights the pre-eminent position the client must take. In a recent study on the perceptions of construction firms in Singapore on the IS0 14000 environmental management standard, Tan (1997) [10] found that whereas the contractors professed their awareness of issues relating to sustainable construction, they were only taking action where they would otherwise infringe existing statutory regulations or charges such as avoiding the soiling of roads and the illegal dumping of waste. He concluded that the industry would only take action to protect the environment when the client demands it.

3 Potential of Procurement Approach

Sustainable construction or aspects of it may be imposed by legislation, the terms of the construction contract, or the policies of the developer, the designer, the project manager or the contractor. Any construction contract which provides for terms that contravene the legislative obligation would result in the terms being illegal, void and therefore unenforceable. On the other hand, the parties to a construction contract may agree to provide either in the conditions of contract or in the other contract documents, the obligation to achieve sustainable construction or aspects of it. Finally, the developer, the designer, the project manager or the builder can voluntarily adopt a policy to achieve sustainable construction.

3.1 Procurement Options

In the division of the legal responsibility in a construction contract between the developer and the contractor, three generic approaches to the procurement of construction projects may be considered. First, the developer may choose to bear all the responsibility for the design, workmanship, materials, methods of work and site operations. The client exercises maximum influence over the project by playing the role of designer and builder and employing workers to do the physical work. This arrangement requires the developer to enter into employment contracts with all the workers. This *Employment Contracts Arrangement* is not practised in Singapore.

In the Employment Contracts Arrangement, the developer has the full responsibility and therefore control of the design, workmanship, materials, methods of work and site operations. Accordingly, if the developer has a strong policy which promotes sustainable construction, this policy is likely to be translated into an actual achievement of sustainable construction. Even if the developer does not have such a policy, sustainable construction or aspects of it can still be achieved if the designer or the project management team engaged by the developer promotes and incorporates sustainable construction in their proposals to the developer.

In the second approach to the procurement of the construction project, the developer retains the design responsibility which includes prescribing for the necessary workmanship and materials, but engages the services of a contractor to do the builder's works. The contractor's responsibility would then be for methods of work and site operations. This arrangement is known as the *Traditional Approach.* This is popularly used in Singapore (as well as in the UK from where the procedure originated) by both the private and the public sectors of the construction industry.

In the Traditional contracts, the developer has control over the design, workmanship and materials. The developer who wants to promote sustainable construction can instruct its designers to incorporate features of sustainable construction in their designs and specifications for workmanship and materials. The developer, however, cannot interfere with the contractor's control over methods of work and site operations, otherwise the responsibility for any delay or defective works arising from the developer's instructions to change the method of work or site operations would revert to the developer. Whether the methods of work and site operations would follow the principles of sustainable construction is left to the contractor to decide.

In the third generic form of construction project procurement, the developer does not have any responsibility for design or construction because all the responsibility for the design, workmanship, materials, methods of work and site operations is allocated to the contractor in a *Design-and-Build Contract.* In recent years, the design-and-build contract has been gaining popularity with the developers in Singapore. It is favoured by the CIDB as a potential contributor to the effort to enhance construction productivity owing to the likelihood that it will result in buildable designs. It has been used on several public-sector projects as, led by the CIDB, the main public clients have declared their commitment to that procurement approach.

In a Design-and-Build arrangement, the developer relinquishes his responsibility and control over the design, workmanship, materials, methods of work and site operations of the project. The developer would instruct the contractor on its requirements and available budget. In response, the contractor produces the end product with everything under its control. Accordingly, the decision as to whether sustainable construction should be pursued is left to the contractor to make.

4 Potential of Contract Forms and Other Documents

The usual contract documents used in a construction project include the standard form of contract containing the articles of agreement and the conditions of contract. In Singapore, there are two standard forms in use. The Singapore Institute of Architects (SIA) Form of Building Contract (SIA Form) is used in the private sector. There are two forms, namely, the Lump Sum Contract form and the Measurement Contract form. They are used for Traditional contracts. The other standard form of contract is the Public Sector Standard Conditions of Contract (PSSCOC) which is used by public-sector clients. It is used for Traditional contracts and, with necessary amendments, for Design-and-Build contracts.

The other common contract documents for a construction project include the drawings, specifications and Bills of Quantities, if applicable. Finally, a construction contract may also include ***ad hoc*** documents such as letters setting out the agreements reached during tender interviews or other negotiation sessions.

There are generally two ways in which sustainable construction may be prescribed in a construction contract. Firstly, by using the quality prescription specifications where the known standards in respect of design, workmanship, materials, methods of work and site operations which allow sustainable construction to be achieved may be specified. Secondly, by using the performance prescription specifications where the known states of achievable sustainable construction are specified for compliance in respect of design, workmanship, materials, methods of work and site operations.

The discussion in the rest of this section is on how the contract documents may be used in Traditional contracts to procure sustainable construction since the Employment Contract Arrangement is not used in Singapore and Design-and-Build Contracts place all responsibility for the completion of the project on the contractor. The discussion is based on the assumption that the developer is motivated by a policy to pursue sustainable construction.

The SIA Form and the PSSCOC oblige the contractor to comply with all existing statutes and regulations, including any legislation which supports sustainable construction. Thus, by clause 7(1) of the SIA Form:

> The Contractor shall comply with ...any instrument, rule or order made under any written law applicable or any regulation or bye-law of any Government authority or any statutory undertaker which has any jurisdiction with regard to the Works or with whose systems the same are or will be connected.

The corresponding part of clause 7(1) of the PSSCOC has a similar provision. Examples of such statutory provisions for sustainable construction includes prohibition of the disposal of waste through burning in open fires.

In Singapore, two aspects of design which may be considered to be in support of sustainable construction and which have- found their way to the contract documents, namely, the drawings and the specifications, are buildable design and the use of pre-fabricated components. In both instances, the percentage of wastage in materials and labour should be reduced. Any other design in support of sustainable construction may be introduced into the contract documents in the same way.

Although in the Traditional contracts, the control of the methods of work, temporary works and the site operations rest with the contractor [See clause 2(1) of the SIA Form and clause 4.2 of the PSSCOC Form], it is possible for the architect to instruct the contractor to vary the temporary works or methods of working where this is so desired by the architect or the employer under clause 1(4)(b) of the SIA Form. However, this is not expressly provided under the PSSCOC although clause 2.1(1) provides that the authority of the Superintending Officer shall be that stated in or necessarily to be implied from the Contract.

Therefore, it is possible for the Employer using the SIA Form to oblige the contractor to use temporary works and work methods which produce sustainable construction but the contractor must be compensated according to clause 2(3). The clause provides that:

> If any accident, loss, liability, claim or damage subsequently occurs as a result solely of the use of the methods of working or temporary works ordered by a direction or instruction of the Architect under sub-clauses l(3) and (4) of these Conditions and sub-clause (2) hereof . . . the Employer will indemnify and if appropriate pay compensation to the Contractor in respect of the same, provided that the accident, loss, liability, claim or damage would not have occurred if the Contractor's preferred or previous methods of working or temporary works had been used, and provided further that the Contractor has complied with the Architect's direction or instruction with due skill and care.

Another area in which the developer may exercise control to promote sustainable construction is in respect of the plant and equipment used by the contractor to carry out his work. Currently, the standard forms require the contractor to enter into an agreement with the owners of any hired or hire-purchase plant and equipment to assign the benefits of the hire or hire-purchase contracts to the employer before the contractor may bring such plant and equipment for use on the site [See clause 16(4) of the SIA Form and clause 24.4 of the PSSCOC]. This requirement may be extended to oblige the contractor to ensure that all plant and equipment to be brought on to the site would accord with the principles of sustainable construction. This must necessarily be accompanied by a provision to compensate the contractor should this requirement result in a delay to the completion of the works or other losses.

5 Discussion

5.1 The Cost-Benefit Equation

The contractor is unlikely to derive significant direct, short-term commercial benefit from the use of sustainable construction methods of work and site operations on a particular project since the contractor has to work within the contract sum. Therefore, there is no incentive for him to pursue a policy of sustainable construction after being awarded a contract. Indeed, Tan (1997) [10] observed that the contractors he interviewed were adopting a "wait and see" attitude. No construction company in Singapore has yet followed Hawken's (1993) [12] advice on the commercial merits of adopting policies of sustainability.

Likewise, the developer may not be motivated to adopt a policy of sustainable construction because he may not derive any direct benefit. Thus, in the medium term, private clients are unlikely to require construction enterprises to adopt sustainable construction practices. However, in Singapore, the procurement policies of public-sector client organisations are likely to make the difference. After large and medium-sized contractors meet the requirement to be IS0 9000 certified by July 1999 before they can undertake public-sector projects, IS0 14000 may be the next milestone which the CIDB and public clients will encourage sizeable construction firms to achieve.

5.2 Other Driving Forces

A possible, more fundamental, driving force of sustainable construction in the private sector in Singapore is the preference and thus, demands, of the potential end-purchaser or user of the completed item. Such persons or organisations may "encourage" the adoption of a policy of sustainable construction by the developer as they express a choice for constructed items built in this way through their approaches to the purchasing of units. However, this would require end-purchasers and users to be knowledgeable about sustainability in general, and sustainable construction in particular. The process of "developing" such a person in Singapore is underway.

In Singapore; a public education campaign is mounted each year (during the *Clean and Green Week).* In the past three years, emphasis has been put on Green *Design* during this week of lectures, seminars, exhibitions and public shows. A few pressure groups also pursue the matter of sustainability throughout the year. A *Green Labelling* scheme has been introduced to inform consumers about products made in a sustainable manner. Moreover, the youth are being made aware of these issues through the educational curriculum. While enlightened purchasers or users (in relation to sustainable construction) will not emerge in significant numbers in Singapore in the medium-term, developers must prepare for the advent of such a person by adopting appropriate policies. In this regard, the procurement approach adopted, and the contractual provisions, offer scope.

Developers may seek to engage only construction firms with demonstrable sustainable construction policies, for example, as in their IS0 14000 certification, or incorporate in their contracts provisions which oblige construction companies to adopt sustainable construction approaches on their projects.

A final driving force is legislation. This will impose obligations on the developer and contractor to pursue sustainable construction policies. In such an event, construction contracts would incorporate provisions aimed at achieving sustainable construction.

6 Conclusion

The issue of sustainability in construction has not yet received significant attention in Singapore. However, owing to the actions of pressure groups and an on-going national public education campaign, the potential end-purchaser and user of constructed items is being made aware of the concept of sustainability. Developers may soon find it commercially necessary to adopt a policy of sustainability. The public client is likely to take the lead by adopting It should be possible for both public and private sector clients to achieve their aims in this connection through the inclusion of appropriate provisions in the forms of contract which they adopt on their projects.

7 References

1. Ofori, G. (1992) The environment: The fourth construction project objective? *Construction Management and Economics,* **10**, 369-395.
2. United Nations Centre for Human Settlements (UNCHS) (1993) *Development of National Capacity for Environmentally Sound Construction.* Nairobi.
3. Chartered Institute of Building (1989) *What Are You Doing About the Environment?* Ascot.
4. United Nations Conference on Human Settlements (Habitat *II)* (1996) *The Habitat Agenda: Goals, principles, commitments and Global Plan of Action.* Istanbul, Turkey, 3-14 June.
5. Kibert, C.J. (1994) Establishing principles and a model for sustainable construction. In *Proceedings, First International Conference **of** CIB Task Group 16 on Sustainable Construction,* Tampa, Florida, 6-9 November, pp. 3- 12.
6. Hill, R.C. and Bowen, P. (1997) Sustainable construction: Principles and a framework for attainment. *Construction Management and Economics,* **15**, 223-239.
7.‘ Ministry of the Environment (199 1) *Singapore's Green Plan: Towards an Environment City a draft proposal.* Singapore.
8. Ofori, G. (1993) The environment as a construction project objective. In Briffett, C. and Sim, L.L. (eds.) *Proceedings: Seminar on Environmental Issues in Development and Conservation,* Singapore, pp. 52-56.
9. Low, C.K. (1996) Environmental Friendly Architecture in Singapore. Unpublished Dissertation, National University of Singapore.
10. Tan, A.T.K. (1997) IS0 14000: A Practical Approach for the Local Construction Industry. Unpublished Dissertation, National University of Singapore.
11. Ng, P.W.M. (1993) Environmentally sustainable construction. In Lee, S.E., Tham, K.W. and Sim, L.L. (eds.) *Green and Healthy Buildings.* Centre for Building Performance and Construction, National University of Singapore.
12. Hawken, P. (1993) *The Ecology **of** Commerce.* Harper Business, New York.

Matching Contract Procurement Systems to Particular Construction Environments in Developing Countries

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Abstract

Developing countries have now been inundated with an array of emerging contract procurement systems. Against a background of physical, climatic, manpower and other resource limitations, these countries are faced with a fundamental question. Which contract procurement system is best suited to any given situation? Which method of measurement and of payment is then the best match with the selected procurement system? Clients increasingly wish to know which procurement system is most appropriate and upon what criteria or characteristics does this decision depend. The paper attempts to present a methodology based on a number of selected indices which define the specific construction environment, the client's objectives, the status of the client organisation and the nature of the project. The paper uses principally the experiences of Trinidad and Tobago over the last two decades as well as other contracts let in the English-speaking Caribbean.

Keywords: Contract Procurement, Measurement, Payment Monitoring, Scheduling, Payment, Quality and Satisfaction.

1 Introduction

The anglophone Caribbean island-states have had a long and deep dependence on the British legal system and its construction practice. They have therefore developed an intimate knowledge of and a confidence in the contract procurement systems emanating from the U.K. Up to the start of the second world war all its technology, the training of its construction professionals and subprofessionals (technicians), the construction text and reference books, affiliations with professional bodies, all were UK based. The influence of Canada and the United States of America had peripheral impact on the regional construction practice. The impact of the other European states was insignificant, if not non-existent. One may say that our colonial link with the U.K. shielded Trinidad and Tobago as well as the rest of the English-speaking Caribbean from any other external influence. After the second world war, a trickle of US and Canadian Engineering and Architectural graduates returned and presented a conduit to the North American influence.

The US military involvement in the region during and some time after the great war served to intensify this influence. The Canadian influence was to increase due to increased opportunities for students to study at Canadian universities. But the impact also increased due to the presence of the Canadian International Development Agency (CIDA) as an aid vehicle and later due to Canadian firms which began to appear. They were to come as joint venture arrangements or as independent consultants or contractors.

The U.S. involvement was to increase because of the geopolitical dynamics in the region and the axis of influence was to shift to the US as the dominant external influence. The U.S. investment in the petrochemical sector intensified the presence of US firms in the full range of relationships from joint venture, foreign direct investors, design and build contractors, design (engineers and architects), contractor builders and later project managers. US influence in the construction sector and particularly in the evolving contract procurement systems was to become the dominant influence displacing the earlier unchallenged position of the U.K. construction fraternity. This was elevated to even greater status as a result of the multilateral and bilateral lending mechanisms emanating out of the U.S. market. The leading influence can be identified as the IMF, the World Bank and the IADB.

2 Existing Contract Forms

Within the context of the British construction experience the Caribbean and indeed the Trinidad and Tobago construction sector was nurtured in the use of the traditional contract procurement systems. In Trinidad and Tobago the construction sector was very familiar with the different types or forms of contracts in all their variations e.g.

- (i) Admeasurement Contracts, both with Bills of Quantities and with Schedule of Rates.
- (ii) Lumpsum Contracts.
- (iii) Cost plus or reimbursement contracts.
- (iv) Direct labour or labour only contracts.
- (v) All-in contracts.

This classification tells how the works to be carried out shall be measured and hence payment made.

In this context the young construction professional but particularly the client would present the question to the consultant: "Which one is to be chosen in any particular situation?" and "What is the basis for the selection?" Here usually years of experience guides the consultant into a choice even if he/she does not commit to paper or oral defense, the detailed reasoning. But the form of arriving at a choice does not negate the fact that a national system can be constructed to guide the choice. Each system has advantages which would recommend its use and each system has disadvantages that we must be mindful of. Each system would therefore suggest that upon its selection a series of mechanisms or systems must be put in place to minimise the negative effects or obviate the weaknesses or difficulties. In fact the consultant should seek to rank these various systems in the context of the particular project and the project environment. It would follow that for a given situation one contract form would be more suitable or advantages (appropriate) but should we be constrained to choose another contract form the consultant must know what complementary systems must be involved.

3 The Conventional Building Procurement Systems

Up to the mid 1970's the local construction sector had settled into award of contracts of either the following types:

(i) The early master builder contract, the precursor or forerunner of the modern day design and build contract. This procurement system has survived, particularly used with small projects and where the design component is simple or minimal.

(ii) The traditional contract (delivery) system with Consultant/Designer and Builder/Contractor.
Here the design function is separated out from the construction function. In fact there may be two separate design contracts, one with the Architect and other with the Engineer.

(iii) The Package Deal and Turnkey Contract
In this the single contract procurement system ensures the delivery of the works and binds the two parties.

(iv) The Design and Build contract. This procurement system is similar to the turnkey contract in that a single contract binds the parties and circumscribe both the design and the construction aspects.

The favourable or appropriate condition for selection of one of these systems has been discussed by Franks (1984) in a guide to building project management.

The construction boom which Trinidad and Tobago experienced (1974-83) as a direct result of drastic increased oil (petroleum) prices was to witness a new advent of contract procurement systems. The author (Suite, 1993) dealt extensively with the emerging contract procurement system in showing what specific conditions led to the introduction of each new emerging procurement system.

4 New and Emerging Procurement Systems

4.1 Multiple or Separate Contracts

Large construction projects were in a number of cases divided into several discrete and separate contracts. Infrastructure projects easily lent themselves to this strategy. Road construction projects were segmented into smaller lengths so that several local small contractors could participate. This device permitted local contracts to meet bond and insurance and undertake a portion of the work which was well within their capacity. It proved useful in containing haemorrhaging of scarce foreign exchange since a large contract would in many cases rule out local contractors thereby necessitating the use of foreign contractors.

It must be admitted that this strategy of multiple contract award brought with it a greater opportunity for conflicts, disputes, delays and even litigation. The multiple contract system required greater monitoring, coordination and scheduling: It was to lead to greater use of project managers.

4.2 Project Management

The increased complexity and the need to execute projects on time and within budget have led to the emergence of two forms of the Project Management Procurement Systems, the Project Manager as Main Contractor and the Project Manager as Main Consultant. A great deal has been written on both these forms

4.3 Design, Finance and Construct Procurement (DFC)

The end of the construction boom in Trinidad and Tobago saw the next wave of contract procurement systems being introduced. This new service revolved around the situation in which these clients, often the State as central government or as statutory authority, did not have immediate access to the funding but nevertheless wanted the works to be carried out. This was the subject of an earlier paper (Suite, 1987). In this system the contractor provided the design, the finance and the construction, to be paid after the project was completed. This was the Design, Finance and Construct (DFC) system.

4.4 Equity Financing

Equity financing was to be introduced into Trinidad and Tobago as the next initiative of the private sector, with the financial institutions acting as the local partner. This spawned several systems, the best known is the Build, Own, Operate and Transfer (BOOT). Others in the series included the Build, Own, Operate (BOO) and the Build, Own, Lease, Transfer (BOLT). In this procurement system and its several derivatives, the contractor is both a developer and an investor. In some instances he may be prepared to operate the facility (BOOT) for some period before transferring ownership back to the intended client or owner. The contractor as investor provides the funding as well as the design and construction. In one case (BOOT) the contractor then operates the facility for a period to recover his investment and a return on the investment after which, title or ownership is transferred to the original client. In another instance (BOLT) the contractor leases the facility to the client who pays a rent or lease for use of the property for a period after which title is transferred to the client.

Initially, here in Trinidad and Tobago, it was the state through the central government or the statutory authorities, short of funds, that sought to enter into these arrangements. Today, private sector firms have began to enter into these arrangements. The present situation has produced two interesting examples. In one instance, the central government has leased a building from a private company which built the facility. This permitted the state to end a number of rental arrangements for several offices which are all now housed in a single building.

In another instance a private company that is involved in property development has recently constructed an office block to serve as the regional headquarters of a multinational company operating locally. The multinational has entered into a lease as part of a BOLT arrangement.

What has emerged is four different types of procurement systems available to the client.

- (i) Traditional Procurement System - (Client financing)
  - (a) Master Builder
  - (b) Traditional Contracts (Separation of functions)
  - (c) Package Deal/Design and Build/Turnkey
- (ii) Project Management Based Procurement System
  - (a) Multiple or Separate Contracts
  - (b) Project Manager as Main Consultant
  - (c) Project Manager as Main Contractor
- (iii) Deferred Payment or Debt Financing Contract Procurement
  - (a) Design, Finance and Construct
  - (b) Construct Financing (Consortium)
- (iv) Equity Financing/Joint Venturing (Contractor Financing)
  - (a) Joint Venturing (Partnering)
  - (b) Build Own Operate (BOO)
  - (c) Build Own Operate Transfer (BOOT)
  - (d) Build Own Lease Transfer (BOLT)

The question will forever be on the agenda. Which procurement system is best for a given system? The author in studying the Caribbean experience has attempted to deal with this issue in pointing to developing trends (Suite, 1994).

5 ‘The Emerging Picture

We are in a position to summarise before commencing by analysis.

The different measurement and hence payment system identified must be matched to the procurement systems.

Admeasurement		Traditional Payment	(a)
Lumpsum		Project Management	
Cost Plus (Reimbursement)	x	Deferred Payment	(b)
Direct Labour		Equity Financing	
All-in Contracts			

Several environmental factors determine how the analysis will begin and how it will proceed.

We may list some of these factors which will almost preselect, direct or restrict the selection.

Question # 1 <u>Financing</u>

Does the client/owner have the funding? If he does, then traditional procurement or project management immediately recommend themselves. If he does not, then he must have recourse to deferred or debt financing or equity financing.

Question #2 <u>Time</u>

Is completion time critical (of the essence), requiring close monitoring and dovetailing of schedules?

Question #3 <u>Technology</u>

Is the project complicated or requiring new technology or highly specialised knowledge, experience and skill, are there a few competent firms?

Affirmative answers to questions #2 and #3 would both favour either the Design and Build/Turnkey/Package Deal or the Project Management procurement systems. The former would permit fast tracking and single point responsibility and the latter would require continuous monitoring and synchronised scheduling.

Question #4 <u>Familiaritv</u>

Is the client/owner almost totally unfamiliar with the needs of the facility, and has no in-house experience or competence?

An affirmative answer would suggest a need for greater reliance on consultants. The traditional procurement system or the Project Management Systems would offer advantages.

No Finance Available to Client/Owner	Time of the Essence Client non-familiar New Technology Finance may not be able to raise	Equity Finance (BOOT) (BOLT)
	Time of the Essence Client Familiarity Standard Taking Finance can be raised in the future	Debt Financing D.F.C.
Client/Owner Finance Available	Time is of the Essence	Project Manager as Main Contractor Design and Build
	Client non-familiarity large complicated project New Technology	Project Manager as Main Consultant
	Technology well established	Traditional specialisation

Question #5 Straightforward

Is the design process straightforward or completed? Can all the work components be accurately anticipated and measured? Is the scope of the works well defined?

Nature of items clear; Sequence clear but quantities not precise	Admeasurement contract
Design incomplete, Sequence and scope of works not clear	cost plus Reimbursement

If the Principal items and scope of works are well established but a number of smaller items cannot be accurately evaluated then a lumpsum may best cover these.

Question #6 Capacity

Does the client/owner have capacity in terms of equipment and/or materials required for the project?

An affirmative answer would suggest a direct-labour contract.

A negative answer would suggest an all-in contract

One can ask several other questions to assist in the optimum matching of contract measurement and payment system with available procurement systems.

The first task with which the client and/or his consultant is faced is to select the procurement system.

Matrix #1 Questions

Procurement System	Finance	Time	Technician	Familiarity	Straight-Forward	Client Capacity
A. Traditional Systems						
. Master Builder	-		-	-	-	-
. Traditional/Separate Function	-	-	-	-	-	-
. Package Deal/Design and Build/Turnkey	-	-	-	-	-	-
B. Project Management						
. Multiple/Separate Contracts	-	-	-	-	-	-
. Project Manager, Main Consultant	-	-	-	-	-	-
. Project Manager, Main Contractor	-	-	-	-	-	-
C. Deferred Payment/Debt Financing	-	-	-	-	-	-
Design, Finance and Construct	-	-	-	-	-	-
Consortium Financing		-	-	-	-	-
D. Equity Financing						
Joint Venturing	-			-	-	-
Build, Own, Operate, Transfer			-	-	-	-
Build, Own, Operate		-	-	-	-	-

Having set a ranking system and selected the most appropriate procurement system, the next task is to decide how the work items or the entire works are to be evaluated and measured. This will determine how progress will be monitored and schedules of completion time tracked (and updated), how quality of work will be determined. Above all, upon what basis will monies be paid.

Another matrix of contract form vs questions, would facilitate the selection.

Matrix #2

Contract Form	Complete Design	Quantities easy to Identify	Time	Technology	Straight-Forward	Client's Capacity
Admeasurement						
Bills of Quantities	-	-	-	-	-	-
Unit Rates	-	-	-	-	-	-
Lumpsum	-	-	-	-	-	-
Cost Plus/Reimbursement						
Cost plus fixed fee	-	-	-	-	-	-
Cost plus percentage	-	-	-	-	-	-
Cost plus fee plus percentage	-	-	-	-	-	-
Direct Labour (Labour Only Contract)	-	-	-	-	-	-
All-in Contract	-	-	-	-	-	-

It would follow that a number of questions asked to assist in selecting the procurement system are again relevant in respect of how the work is to be measured. The two matrices are therefore limited. One may conclude that some procurement systems are more easily matched with some forms of measurement.

Matrix #3

Procurement System	Risk
A. Traditional System	MB carries all risks to deliver
Master Builder (MB)	Risk divided between Consultant(s) and Contractor(s)
Separate Financier	
Package Deal, etc.	Contractor carries all risk to deliver
B. Project Manager	
Multiple Contract	Risk shared by each contractor and consultant
Project Manager - Main Consultant	Risk shared by Project Manager
Project Manager - Main Contractor	Risk carried by Project Manager
C. Deferred Payment/Debt Financing	
Design, Finance, Construct	Contractor carries all risks
Construction Financing	Risks shared between Financier and Contractor
D. Equity Financing	
Joint Venture	Joint Venture plus share risk
BOOT	Developer carries risk
BOLT	Developer carries risk
BOO	Developer operator carries risk
E. Admeasurement Contracts	Contractor carries risk
F. Lumpsum	Contractor carries risk
G. Cost Plus Reimbursement	Client/owner carries risk
Direct Labour	Client/owner carries risk
All-in Contract	Contractor carries risk

Summary

Selecting a contract procurement system and a measurement/payment system is a question often posed by both student/young construction professional and client. Some projects within a given construction climate seems naturally to suggest one combination. Some contractors and consultants have preferences. But the final choice must be based on a number of internal or inherent factors specific to the project type. The choice must also be made based on the prevailing external or environmental factors, including availability of finding, technology, contractor and consultant experience and skill, state of national economy, urgency of the project, to list but a few. The selection must be justified, based on objective answers to a series of relevant questions. Nevertheless, the system being advocated would generate a priority ranking of procurement types, each one offering advantages and disadvantages. In some cases the client may see an upper hand in transferring the risk to the contractor, should one procurement system be selected. The contractor may prefer yet another because his risk would be reduced. Should the final section go either way both parties must know what are the risks and how they can be reduced. In essence each procurement system has apportioned the risk differently. This is the central issue to determine.

One may ask what is the nature of the risk? Obviously there are several different types of risk. There is the risk inherent in construction difficulties (on site). There are risks associated with the market such as change in prices or even the need for the facility and hence the viability of the project once completed i.e. that the assumptions, upon which the feasibility was predicted were valid (then) and realised (later).

Now risk relates to the uncertainty. The issue is therefore who carries the responsibility for factoring in the uncertainty? Contract procurement systems are therefore different devices for realising the project (works) with differing allocation of risks.

References

Frank, J. (1984). Building Procurement Systems. The Chartered Institute of Building. **1984.**

Suite, W.H.E. Recent Trends in Contract Procurement System in Trinidad and Tobago, A Case Study. 7th International Symposium CIB. **1993 (W-65).** Vol. 2, pp. **737-748.**

Suite, W.H.E. **(1987).** Finance, Design and Construct. A Construction Management Package. 5th International Symposium on Organisation and Management of Construction. CIB W-65. London. Proceedings pp 92-102. September 1987.

Suite, W.H.E. (1994). Evolving Contract Procurement Systems, Pitfalls, Challenges and Opportunities. Presented at the 8th Annual Technical Conference of the Association of Professional Engineers of Trinidad and Tobago. Nov. **15-17, 1994.** pp. **13.**

Building Procurement and Organisational Learning - Missed Opportunities

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Abstract

A series of recent Australian studies into construction time performance revealed that neither the building construction companies nor the client undertook any meaningful organisational learning activities to ascertain what could be learned from the experience of managing building and civil engineering construction projects. Post project evaluation studies were not required for the building and civil engineering projects but this was not the case for the process engineering projects. A post project evaluation was expected by clients and provided as part of services procured for process engineering projects.

Organisational learning codifies experience gained by individuals and teams in a form that adds value to an organisation. Learning is an asset, comprising intellectual property, which can be reused to add competitive advantage. It is also an effective means by which innovation can be introduced to organisations. Innovation is often generated from team members' personal experiences brought with them from one temporary organisation to another.

It is argued that the building industry should not only initiate post project evaluation but also a process of continuing organisational learning during the entire life cycle of the project.

Keywords: Procurement, Organisational Learning, Construction Time Performance, Competitive Advantage.

Introduction

Clients should expect efficiency gains due to product innovation, changed work methods (process innovation) and the positive impact of competition derived from companies

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capitalising upon their organisational knowledge assets. Also, clients should expect advice that allows them to achieve more sustainable projects with lower life-cycle costs, improved quality of product delivered and quicker construction times. Clients should, therefore, expect improvements in the project delivery process.

Research into changes in construction time performance of Australian construction projects between 1979 to 1992 revealed that construction time performance productivity increased between 19% and 38%. This productivity gain can be explained by technical improvements in the process of managing construction and team relationships improvement those involved in the construction process (Walker 1995).

The construction industry has no formalised process, insisted upon by the client, to ensure that reflective learning takes place in the form of rigorous project reviews. In a series of studies reported upon by Walker and Sidwell(1996) only 6 projects out of 45 had undertaken formal post project evaluation and these 6 projects were process engineering projects. Thirty-three projects were building construction and the remaining six were civil engineering projects clearly indicating that the construction industry pays little attention to finding a way to codify or record lessons learned.

A contrast was found between process engineering projects and building and civil engineering projects, which may be explained by the nature of the commissioning exercise for process engineering projects. These projects entail the commissioning of plant and equipment which process hazardous materials. Clients and contractors feel a greater incentive to ensure that lessons learned result in improvements to these projects, which are constructed for maximum safety levels when operational. Clients, such as the major oil companies are sophisticated procurers of construction services. British Petroleum (BP) and Mobile regularly use partnering and/or strategic alliances with a critical emphasis on project partners meeting strict quality provisions for audits of the construction process in order to 'capture' lessons learned (Prokesch 1997). This does not appear to be the case in the construction industry, which has a client profile where repeat projects are less likely to be activated within several years. It is, however, interesting to note that the mean construction time performance of the process engineering projects performed equally with the other projects (Walker 1997a).

The issue of post project evaluations not taking place poses interesting questions. For example, is the current procurement system adopted by the construction industry:

- Leading to a lack of organisational learning ?
- Depriving clients of value from experience gained ?
- Depriving the construction development team (suppliers, contractors and consultants) of the opportunity to enhance their competitiveness?
- Inhibiting construction development teams applying innovative processes and products?
- Inhibiting sustainable development?

The Value of Learning

"Complacency bred of past success leads to unexamined assumptions, blind spots and taboos that not only block the creation of new mandates among managers but also make it very difficult to sense, communicate and use intelligence about future trends." Marchand's (1997) comment underscores the need for strategic thinking about how to improve the provision of built projects. It is one thing to undertake an informal review of lessons learned but quite another to build a system where learning is readily available and easily communicated to those faced with problems and issues where past learning would be of help. A structured and codified way of capturing learning is needed as no learning can take place in an organisation unless it possesses a proper memory system (Tsang 1997, p78).

This is a leadership issue. It is a leader's task to design a learning process whereby people throughout the organisation can deal with and master the critical issues they face (Senge 1992, p345). Senge also stresses that shared vision is the product of a process that develops from extensive and often intensive communication between team members about each person's perception of what has, and is, occurring. This is an organisational learning process. Through communication of different and parallel perceptions of 'history', teams can gain a truly shared vision that builds their own understanding of 'truth' (Senge 1992, p231). Thus shared objectives are grown and joint commitment strongly established.

Team members who take the time to share their views of events have a more valuable collective view of 'the facts' (Senge 1992, p235). This added value allows them to be more flexible and rapid in amending their response to changing circumstances. This may help explain why a recent study found that there was a 33% improved mean construction time performance for construction management teams who exhibited a very high level of flexibility in adapting plans to meet new conditions (Walker 1996). Fisher highlighted the importance and value of organisational learning in the construction industry with an interesting insight into a Construction Industry Institute (CII) research project on a process for modelling lessons learned. She makes the point that *"Owners and contractors must depend on job end reports and/or rapid communication to transfer lessons learned from project to project. In today's fast track project environment, this is virtually impossible without a formal, systematic process that is to some extent automated."* (Fisher 1997, p36).

In a paper on organisational learning from natural disaster management, Carley and Harrald (1997) report on the activities of the Red Cross and other US agencies dealing with disaster relief. They state that the Red Cross has difficulty in measuring effectiveness for post project evaluation because they use shallow performance measures such as 'X' meals served, and 'Y' persons sheltered. The learning achieved only identified was what was done and not what was needed to be done. Learning must be based upon deep reflection and critical analysis not shallow metrics. Context needs to be explored and reviewed so that past experience can be used to model new situations. This allows the additional benefit of providing a framework for simulation testing.

Constantine (1993) offers an interesting technique for use in recording organisational learning, which he refers to as 'Design by Walking Around'. In this approach a continuous record is kept of what the group does. This is similar to what is understood as a 'global method statement' in the construction industry (Walker 1997b). Records of the process, strategy, and other key management approaches together with the success or otherwise of outcomes are maintained. The recording medium is unimportant, but essentially three sources of 'bins' are created for storing ideas pertaining to problematic issues. In one 'bin' success stories are recorded noting reasons for success. In another 'bin' failures are similarly recorded; again reasons leading to this outcome are recorded. The third 'bin' contains deferred decisions, in-progress, and undecided responses to issues and problems. This 'bin' can contain gems of knowledge to be used at a later time because they were not implemented due to current circumstances and environments not being conducive to success. This approach offers a model for undertaking continuing review and learning. In this way, organisational learning can be shared and maintained for easy access.

It is clear from the general management as well as construction management literature that the value of learning from past experience plays a crucial role in building process improvement. It is equally clear that this activity needs to be encouraged and structured into the management process. If companies are not initiating this to the extent required for significant and sustained productivity improvement, then clients should consider making the process a contractually required part of services provided by construction teams.

Innovation and Organisational Learning

Nam and Tatum (1997), in a study of 10 innovative projects in the USA, stress the importance of leadership by the client (owners) of the facility in fostering innovation. Seven out of the ten projects case studies showed owner leadership and involvement as being pivotal in adopting innovative practices. They believe that technical competence is largely responsible for this propensity for innovation. Further, their study indicates that in eight out of the ten cases *"managers with the authority for approval of key ideas in the construction innovation had a high level of technical competence"* (Nam and Tatum 1997, p265). They also found that technologically competent managers devoted time to continued learning about technical matters. This can be achieved through undertaking post project evaluation. Nam and Tatum (1997, p267) also stress the need for slack resources to be made available in the form of time or funds. Again this can be effectively used to fund a post project evaluation process.

Another popularised management theory of the early 1990's was re-engineering. This concept espoused by Hammer and Champy (1994), explores the tension between what is referred to as 'inductive' and 'deductive' thinking applied to business process improvement. *Inductive* thinking is described as the ability to first recognise a powerful solution and then seek the problems it might solve (Hammer and Champy 1994, p84). Thinking *deductively* about technology not only causes people to ignore what is really important, it also gets them excited about technologies and applications that are, in fact, trivial and unimportant (Hammer and Champy 1994, p86). Their propositions were widely regarded as a radical approach because they essentially advocated a revolutionary zeal in starting again from scratch in developing process improvement. Hilmer and Donaldson (1996), however, caution against mindlessly adopting the latest American Business ‘fad’ or ‘quick fix’. They rightly make the point that shallow thinking does not lead to productive organisational learning. While it is perfectly valid to question assumptions they do need to be abandoned. In fact, being innovative requires us to deeply consider how circumstances may have changed from those underpinning existing processes, and making appropriate flexible changes to accommodate new realities. This again requires reviewing and learning from the past, suggesting that clients who encourage this kind of review can contribute to industry improvement through organisational learning.

Sustainable Construction Principles and Organisational Learning

In describing an Environmental Management System (EMS), Hill and Bowen (1997, p236) identify as a key requirement that *“an audit report provides an essential information feedback loop to management who can take corrective action to address weaknesses of the EMS”*. Several aspects of management processes are included in a four ‘pillar’ EMS system advocated by Hill *et al* (1994). Organisational learning can address sustainable construction principles through designing to meet the clients needs and objectives to minimise complexity which could demand unnecessary resources. In this way it can be seen to be in accord with constructability principles (McGeorge and Sidwell 1996). Sustainability seeks to eliminate unnecessary waste including re-work. In this way it can be seen to accord with re-engineering principles and waste minimisation philosophies. All these aspects require management procedures where plans are established, monitoring takes place which informs appropriate decision making. While this process is routinely followed during the construction phase for time, cost, quality and safety, it rarely follows that a post project evaluation is undertaken to learn from assessment of the project as a whole. Thus, a crucial opportunity for organisational learning is missed.

There is a growing awareness of the impact upon society’s long term future of the process of developing the built environment. Concepts of ‘sustainable design’ and ‘sustainable construction’, which are part of a ‘green building’ agenda, are becoming more important to customers and clients who wish to appear supportive of, if not actually practising principles of sustainability. This requires designers and all parties of the development process to learn from past lessons and best practice principle, to promote and develop a sustainable built environment. Levin (1997) lists common features of ‘green building’ as practised in the USA. These include:

- energy conservation features, both passive and active in terms of energy efficient equipment;
- water conservation features including low consumption and use of ‘grey’ or recycled water;
- low chemical emitting materials for improved air quality;
- less environmentally destructive site development to preserve natural habitats, protect excess water run-off and changes to water tables;
- on-site waste water treatment;
- reduced ozone and fossil fuel emissions;

- life-cycle assessment approaches to material use and recycling;
- regulatory environmental impact assessment of the total building;
- regulatory recycling and waste minimisation provisions for building materials and waste products.

Baldry (1997) describes the contribution that project managers can make in supporting 'green building' principles. He cites the project manager's influence *"… to plan a procurement and resource acquisition route which relies upon ethical and equitable commercial relationships and the pursuit of efficient resource conversion"*. Interestingly he cites the 1992 Maastricht Treaty provisions for a 'precautionary principle' relating to actions that should be undertaken to rectify environmental damage at source. He notes that raising enlightenment amongst designers and constructors to meet or exceed the treaty's provisions is somewhat tempered by stakeholders' needs but he indicates that there is a clear responsibility to actively monitor the development and actualisation of environmentally sustainable design and construction. Baldry identifies the project manager as one independent team member that can exert influence of the design, monitoring and control to improve sustainability. His raising of ethical issues lends weight to the argument that building owners and clients are missing an opportunity to contribute to improvements to the environment in which we all share. This supports the view that organisational learning about the impact of construction upon the natural environment is important. Perhaps enlightened clients could specify in their terms of engagement that their project manager, as an independent professional, could lead the process of undertaking a post project evaluation.

Numerous tools exist for undertaking an evaluation of various aspects of 'green building'. Graham (1997) provides a comprehensive analysis of eight tools and systems used to measure and assess various aspects of environmental impact. He concludes that these tools can be constructively used to model likely impact upon the environment for proposed design and construction strategies. Yates (1997), agrees and provides an interesting analysis of six years of use of The Building Research Environmental Assessment method (BREEAM) which was developed in the UK. The tool also links cost savings with environmental impact. He cites a study of 100 interviews undertaken by the Deloite and Touche Consulting Group, which reveals interesting user motivations. Interviewees comprised a range of BREEAM current and potential users who discussed reasons for using the system. General societal goals, such as ensuring that best 'green building' practices are being applied, and more client specific goals, such as direct cost/benefit gains made from applying 'green building' principles, were cited. While Yates has a commercial interest in promoting the use of BREEAM specifically, it is interesting that large numbers of clients and building owners are concerned about 'green building' issues and are willing and keen to apply them.

Discussion

This paper highlights the need for improved production through both incremental productivity improvement (*kaizen* and innovation) and break-through improvements (business process improvement). Improvement in terms of sustainable construction was also discussed and it was strongly argued that there is a pressing need for practical ‘green building’ principles to be applied such as waste reduction, reduced re-work and other benefits that can be derived from buildability or constructability principals being applied. Other environmental improvements can also be gained to profit not only the building owner or client but also society at large. Sustainability issues were discussed to shed light on the value of this in terms of the contribution to organisational learning and how this can be translated in improvements for users and society.

Research reported on by Walker and Sidwell(1996) and Walker (1997a) indicates that of 75 projects investigated only six had formalpost project evaluations undertaken. Of these six, all were the process engineering projects. This indicates that building and civil engineering clients are not requiring such studies to be undertaken. It was argued that this may deprive all stakeholders of valuable organisational learning which can be used to improve productivity, innovation and adherence to ‘green building’ principles.

Continuing systemic change (for the better) is dependent upon building a permanent learning capacity across as well as within organisations (Kochan and Useem 1992, p404). While project teams tend to be temporary organisations they are made up of individuals who form more permanent teams within their own companies. Clients also tend to have more stable organisations. It has been clearly argued that organisational learning has the capacity to significantly raise productivity. It has also been strongly argued that systematic, codified and structured post project review can reveal valuable lessons, which may be successfully applied or suitably modified to improve productivity in future projects.

There is a stark contrast between a shallow, unstructured and ill-conceived process for harvesting lessons learned from any project and a well-structured and rigorous examination of the ‘history’ of a project. On the one hand lessons learned may be forgotten or transformed in the minds of participants well past a point of shared understanding. On the other hand, not only lessons learned, but also the context surrounding events and the richness of input from numerous points of view can be harvested and put to productive use.

Conclusions

There are few (if any significant numbers of cases) where the client demands, funds, and ensures that harvesting of knowledge gained from one project is available for the next. Various attempts to achieve these aims through partnering or strategic alliances are not addressing the main need - organisational learning.

A number of examples of ways in which organisational learning can be achieved has been offered through post project evaluations and ‘Design by Walking Around’ techniques. Both of these require to be undertaken through deep thinking and analysis rather than shallow or superficial analysis of problems tackled, approaches taken, circumstances surrounding problems and solutions, and strategies or tactics employed.

Clients have the capacity and the means to provide leadership in organisational learning through demanding well conducted reviews of projects to record and communicate lessons learned. The cost of including this requirement is unlikely to be significant, hardly a fraction of a percentage point of project cost. Benefits to be gained from such an exercise can be lasting and significant to the client and project team members.

References

Baldry D. (1997), 'The role of project management in the environmental impact of the building process', Proceedings of the Second International Conference on Buildings and the Environment, Paris, France, June 9-12, 1997, *CIB Task Force Group 8*, **2**, 121-128.

Carley K.M. and Harrald J.R, (1997), 'Organisational learning under fire', American Behavioural Scientist, Jan 40 (3), 310-323

Constantine L.L (1993), 'Work organisation: paradigms for project management and organisation.' *Communications of the Association for Computing Machinery Inc (AC', 36* (10), 34-39.

Fisher DJ (1997), The Knowledge Process, in *Lean Construction,* ed. Luis Alarcon, AA Balkema, Rotterdam, 33-42.

Graham P.M. (1997), 'Assessing the sustainability of construction and development: an overview', Proceedings of the Second International Conference on Buildings and the Environment, Paris, France, June 9-12, 1997, *CIB Task Force Group 8,* **2**, 647-656.

Hammer M. and Champy J (1994). Reengineering the Corporation - a manifesto for business revolution, Allen & Unwin, Sydney.

Hill R.C., Bergman J.C. and Bowen P. (1994), 'A frame-work for the attainment of sustainable construction', *Proceedings of the First International Conference **of** CIB TG 16 on Sustainable Construction, Tampa, Florida, 6-9 November,* 13-25.

Hill R.C. and Bowen P. (1997), 'Sustainable construction: principles and a framework for attainment', *Construction Management and Economics,* E & FN Spon, London, UK, 15 (3), 223-239.

Kochan T.A. and Useem M. (1992), Transforming Organisations, *Oxford University Press,* Oxford, UK.

Levin H. (1997), 'Systematic evaluation and assessment of building environmental performance (SEABEP)', Proceedings of the Second International Conference on Buildings and the Environment, Paris, France, June 9-12, 1997, *CIB Task Force Group 8*, **2**, 3-10.

Marchand D. (1997), 'Looking ahead with strategic intelligence', *Business Review Weekly,* June 16, 80-82.

Nam C.H. and Tatus C..B. (1997), 'Leaders and champions for construction innovation', *Construction Management and Economics,* E & FN Spon, London, UK, 15 (3), 259-270.

Prokesch S.E. (1997), 'Unleashing the power of learning: An interview with British Petroleum's John Browne', Harvard Business Review, September-October, Harvard, Boston, USA, 146-168.

Senge P.M. (1992), The Fifth Discipline, *Random House*, Sydney, Australia.
Tsang E.W.K. (1997), 'Organisational learning and the learning organisation: a dichotomy between descriptive and prescriptive research.', *Human Relations*, Jan 50 (1), 73-88.
Walker D.H.T. 1994, An Investigation into Factors that Determine Building Construction Time Performance, PhD thesis, *Royal Melbourne Institute of Technology*, Victoria, Australia.
Walker D.H.T. (1996), 'The Contribution Of The Construction Management Team To Good Construction Time Performance - An Australian Experience', *Journal of Construction Procurement*, *2* (2), 4-18.
Walker DHT, (1997a), 'Construction time performance and traditional versus non-traditional procurement systems', *Journal of Construction Procurement*, *3*, (1), 42-55.
Walker D.H.T (1997b), Planning for Control in the Construction Industry, (on CD-ROM) *INFORMIT RMIT Press*, Melbourne, Australia.
Walker D.H.T. and Sidwell A.C. 1996, Benchmarking Engineering And Construction A Manual For Benchmarking Construction Time Performance, *Construction Industry Institute Australia*, University of South Australia. Adelaide, Australia.
Yates A. (1997), 'Recent Advances in the assesssment of the environmental impact of buildings in the UK, Proceedings of the Second International Conference on Buildings and the Environment, Paris, France, June 9-12, 1997, *CIB Task Force Group 8*, **1**, 59-66.

Identification of environmental risks and their impact on procurement of construction works

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Abstract
This paper considers the risks by examining the 'controls' imposed by common law on the activities of developers and contractors in their relationship with environmental concerns. The risk is that a control is exercised so as to impose liability on the developer. The term 'developer' is used to describe both entities, which of course in reality may be the same or separate legal persons. The developer inevitably has the status of 'landowner' during the development phase, whereas the contractor probably does not, being merely a 'licensee' of the site.

The paper first examines two recent judgments in the House of Lords to show how the common law has not evolved to protect the interests of neighbours and local residents from the perils and hazards of property development which result in environmental deterioration. The conclusion is drawn that common law provides little control of development activity and inadequate remedy for those injured by environmental deterioration as a result of development. The common law protects only the enjoyment of the adjoining landowner or those injured by the developer's negligence. From the developer's perspective beyond the adjacent landowner, only the criminal law poses any real sanction for environmental deterioration. These substantial risks of criminal liability, which cannot be insured against, require identification and quantification at the procurement stage in the project cycle.
Keywords: Common law, damages, development, environment, liability, negligence, nuisance, Rylands v Fletcher

1 Introduction

It seems that there is inevitably some conflict between the interests of developers and the population affected by development, who may be simply the neighbours, the local community or a much wider community. The common law has restricted the activities of developers where those activities impact on others beyond the site boundary and developed remedies where property, economic or personal rights are damaged. But does the common law generally provide sufficient protection and remedy from environmental deterioration caused by developers? What risks does the common law create that developers need consider during the procurement process?

2 The common law

The common law has created three control or regulatory processes that might provide a remedy for a plaintiff who alleges that the quality of its environment has deteriorated due to property development: negligence, nuisance and the rule of *Rylands v Fletcher.* [1]

2.1 Negligence

The modern law of negligence is largely a creation of the common law courts during the last seventy years. The original policy of the law was simple, yet so much litigation on this theory has taken place. Each person was required to consider its own actions with respect to the impact that action might have on its neighbour, and to refrain from those actions which could reasonably be foreseen as likely to injure that neighbour. Inevitably the question arises: who is to be classed as a 'neighbour' in the circumstances in question? The answer originally provided was that a neighbour was any person who the law recognised as entitled to be considered as likely to be affected by the act, or acts, or omission, which are called in question.[2] Negligence is a tort (civil wrong) designed to provide, within limits, reparation for those injured by the carelessness of others. A negligence claim arises only on actionable damage. Much judicial time has been concerned with restricting the scope of duties owed, the extent of compensation allowed, the size and composition of the class of persons entitled to claim compensation, and the permitted time lapse between careless act and consequent damage. Recent policies of the English court have tended to restrict the scope of negligence claims, but this policy has not been adopted in other Commonwealth jurisdictions.

A plaintiff may have difficulty in establishing the degree of 'fault' necessary to secure compensation. Both private nuisance and *Rylands v Fletcher* avoid this problem by imposing the so-called 'strict' liability. Negligence is not further discussed in this paper.

2.2 Private nuisance

The law of private nuisance was reviewed by the House of Lords in *Hunter and others v Canary Wharf Ltd, Hunter and others v London Docklands Development Corporation.*[3] It is necessary to state the factual background. That part of the River Thames between Limehouse Reach and Blackwall Reach and known to previous generations as the West India Docks used to be the thriving Port of London, but it fell into disuse with the growth in container traffic from the East coast ports. The riverside land became derelict and remained so until the Secretary of State approved[4] a scheme which designated the Isle of Dogs, including Canary Wharf, as an 'enterprise' zone. Under this arrangement virtually any scheme could be constructed by-passing the normal process of development control. An agreement was concluded in July 1986 between LDDC[5] and Canary Wharf Ltd which resulted in the construction of office buildings, including the César Pelli tower, 250 metres tall, on plan about 50 metres square, and clad in stainless steel, together with associated infrastructure works. A new road was constructed, the whole redevelopment process causing much excavation and movement of spoil over a construction period of four years.

The essence of the 'enterprise' zoning was that the normal statutory controls on development were eased or removed altogether thus attracting private property investment funds. Before 1980 and the introduction of enterprise zones, it seems unlikely that development on the scale of Canary Wharf would have taken place without a public enquiry[6] and the opportunity created for local residents to voice their concerns. It may generally be said, that local concerns were overridden in this case pursuing instead the Government's view of the national interest.

The quality of the local environment must have been severely diminished for local people during the main construction phase. In Lord Hoffmann's words:

> "The local residents complain that the construction of the Canary Wharf Tower and the Limehouse Link Road caused them serious disturbance and inconvenience. Firstly, the construction of the road caused a great deal of dust in the air which settled upon their homes and gardens. If they opened their windows, everything in the room was soon covered in a layer of dust. If they hung out the washing in the garden it became dirty again. Secondly, the Canary Wharf Tower interfered with television reception. The great metal-clad tower stood between the BBC transmitter at Crystal Palace in south London and a swathe of houses, mainly in Poplar to the north of Canary Wharf, which lay in the building's electromagnetic shadow. The effect was that many houses could not receive television at all. In others, the quality of the signal was impaired. This state of affairs continued until April 199 1, when the BBC brought a relay transmitter into service. Between July 199 1 and August 1992 the residents had their aerials aligned to the new transmitter and the problem was thereby solved."[7]

The local residents commenced two separate actions against the developers and LDDC. The first action (the 'television action') against the developers was founded on negligence and nuisance and sought compensation for the tall building's interference with television reception. This action failed and is not further discussed. The second action (the 'dust action') sought compensation from LDDC for damage and annoyance caused by dust from the construction operations and was founded on, inter alia, nuisance. There were 690 residents as plaintiffs in the 'television action', and 5 13 in the 'dust action'. The claims had been raised by a substantial group of local residents, including householders who had the exclusive right to possess the places where they lived, whether as freeholders or tenants, or even as licensees. The group included people with whom householders shared their homes, for example as wives or husbands or partners, or as children or other relatives. All of these people claimed damages in private nuisance, by reason of interference with their television viewing or by reason of excessive dust. The court addressed the following question as a preliminary issue of law. Does a plaintiff in an action for private nuisance need to have an interest in the property in question, and if so, what interest?

Lord Lloyd observed that private nuisances are of three kinds. They are nuisance by encroachment on a neighbour's land; nuisance by direct physical injury to a neighbour's land; and nuisance by interference with a neighbour's quiet enjoyment of his land. The basis of a cause of action in nuisance is damage to the land itself. The measure of damages is usually the diminution in the value of the land caused by the damage complained of. That loss is suffered by the owner or possessor of the land. The quantum of that loss was not affected by the number of people on the land. Each member of a family did not have a cause of action: there was only one potential cause of action per home.

It was not disputed that activities which cause dust on a person's property could amount to an actionable nuisance, but who can sue? The traditional answer, said Lord Hoffmann, is that as nuisance is a tort against land, including interests in land such as easements and profits, a plaintiff must have an interest in the land affected by the nuisance. That interest was characterised as 'possession or occupation'. A series of cases over the years have explored the quality of possession or occupation needed to found a claim in nuisance. Lack of title to the land was overcome by a lengthy period of occupation. Wrongful possession against the true owner's interest was sufficient to found an action in trespass or nuisance against a third party. Exclusive possession by the plaintiff was a feature of all the actions in nuisance.

Actions in nuisance should not be confused with actions in negligence. Lord Hoffmann said that negligence was based on *fault* but protected interests of many kinds, whereas liability in nuisance was *strict* but protected only interests in land. The effect of the liability in nuisance being strict, that is independent of any fault, is that it is no defence to a nuisance claim to say that all care was taken not to commit it. The liability arises out of the invasion of the proprietary or other interest in land. [8] The exceptions to these well established principles lay in a Canadian case[9] which had been followed by the Court of Appeal.[10] But there was no good reason of policy why the old rules should be abandoned. Lord Hoffman did not agree with academic writings that had recently suggested that the law on this point should adapt to modern social conditions. On the contrary, any "development of the common law should be rational and coherent. It should not distort its principles and create anomalies merely as an expedient to fill a gap." Without an interest in the property affected by dust, said Lord Hoffmann, the plaintiff residents had no right to sue in nuisance.

The majority of the court were of the view that there was no good reason to depart from the law of nuisance as established in the authorities. A mere licensee had insufficient status to sue in private nuisance. An action in nuisance is only possible by a person who has the right to exclusive possession of the property affected. This means that co-habitees, partners, family members and lodgers without more than a license to occupy property are deprived of any right to sue a developer who harms the environment for such class of persons.

One voice of dissent was heard, that of Lord Cooke. In His Lordship's view the choice being made here was a policy choice, whether to restrict the law of nuisance to its historical position or let it expand at least with respect to who could sue. The law of nuisance had been established before the age of television and radio, motor transport and aviation, town and country planning, a 'crowded island', and a heightened public consciousness of the need to protect the environment. All these were among the factors now falling to be taken into account in evolving the law. It seemed absurd to Lord Cooke that whilst a husband as owner had standing to sue, his wife's occupancy of the matrimonial home was insufficient to found an action in nuisance. Children too should be entitled to relief from substantial and unlawful interference with amenities of their home. He noted developments on the law of nuisance within the USA. Here it was acknowledged that occupancy was a sufficient interest in itself to permit recovery for invasions of the interest in the use and enjoyment of the land.

> "Thus members of the family of the possessor of a dwelling who occupy it along with him may properly be regarded as sharing occupancy with intent to control the land and hence as possessors, as defined in § 328E. When there is interference with their use and enjoyment of the dwelling they can therefore maintain an action for private nuisance. Although there are decisions to the contrary, the considerable majority of the cases dealing with the question have so held."[11]

More recently in *Bowers v Westvaco Corp*[12] family members, including minors living at home, were awarded damages by the Supreme Court of Virginia for dust and vibration nuisance caused by truck-staging operations on adjacent property.

Lord Cooke attempted, in vain, to show that whilst it was accepted that in order to sue in the tort of nuisance it was necessary that the plaintiff have some link with the land. But the court was yet free to define the precise nature of that link. He could see that the adoption of his view might "add marginally to building or operating costs" but that was not an obstacle in adopting "reasonable safeguards in any other field of the law."

2.3 Rylands v Fletcher liability

The liability under the principle of *Rylands v Fletcher* was examined by the House of Lords in *Cambridge Water Co Ltd v Eastern Counties Leather plc*.[13] Eastern Counties Leather (ECL) was incorporated in 1879, and since that date has continued in uninterrupted business as a manufacturer of fine leather, employing about 100 people, all or whom live locally. It has used solvents in that process since the early 1950s, including PCE (perchloroethene) which has increasingly been in common, widespread and everyday use in dry-cleaning, in general industrial use (eg as a machine cleaner or paint-thinner), domestically (eg in 'Dab-it-off') and in tanneries. PCE is highly volatile, and so evaporates rapidly in air; but it is not readily soluble in water. ECL began using PCE sometime in the 1960s, and continued to use PCE until 1991. The amount so used varied between 50,000 and 100,000 litres per year. The solvent was introduced into what were (in effect) dry-cleaning machines and must have leaked into the ground.

Meanwhile, in the later 1970s concern began to be expressed in scientific circles about the presence of organic chemicals in drinking water, and their possible effects. The Directive (80/778/EEC) relating to the Quality of Water intended for Human Consumption was issued on 15 September 1980. UK regulations were made in 1989.

The prescribed maximum concentration values for PCE has been 10μg/litre since 1 September 1989. The United Kingdom values have been brought back into harmony with the WHO Tentative Guideline Values of 1984. Before publication of these papers little was known about this subject.

Cambridge Water Company's (CWC) claim against Eastern Counties Leather (ECL) for contamination of percolating water caused by leaking solvent (PCE) was based on three alternative grounds: negligence, nuisance and the rule in *Rylands v Fletcher*. The trial judge dismissed CWC's claim on all three grounds-on the first two grounds, because ECL could not reasonably have foreseen that such damage would occur, and on the third ground because he held that the use of a solvent such as PCE in ECL's tanning business constituted, in the circumstances, a natural use of ECL's land. The Court of Appeal, however, allowed CWC's appeal from the decision of the judge, on the ground that ECL was strictly liable for the contamination of the water percolating under CWC's land, on the authority of *Ballard v Tomlinson*.[14] It was against that decision that ECL appealed to the House of Lords. The question considered by the House of Lords was whether foreseeability was an essential element of liability under the principle of *Rylands v Fletcher*.

In order to consider the question in the present case in its proper legal context, it was desirable in Lord Goff's judgment to look at the nature of liability in relation both to the law of nuisance and the rule in *Rylands v Fletcher*, and for that purpose to consider the relationship between the two heads of liability. Since there is a close relationship between nuisance and the rule in *Rylands v Fletcher*, Lord Goff first considered whether foreseeability of damage is an essential element in the law of nuisance.

The principles of the law of nuisance have been discussed above. Lord Goff noted the original view of nuisance as a tort to land and that it had been distorted by cases involving claims for personal injuries which should have been brought in negligence. Historically nuisance was a tort of strict liability. When Blackburn J had given judgment in *Rylands v Fletcher* he had not regarded it as a revolutionary decision. He was not stating new but existing law, as is apparent from his judgment He was concerned in particular with the situation where the defendant collects things upon his land which are likely to do mischief if they escape, in which event the defendant will be strictly liable for damage resulting from any such escape. It followed that the essential basis of liability was the collection by the defendant of such things upon his land; and the consequence was a strict liability in the event of damage caused by their escape, even if the escape was an isolated event.

The strictness of liability in nuisance had been reduced by the concept of 'reasonable user'-the principle of 'give and take' as between neighbouring occupiers of land. If the user is reasonable, the defendant will not be liable for consequent harm to his neighbour's enjoyment of his land; but if the user is not reasonable, the defendant will be liable, even though he may have exercised reasonable care and skill to avoid it. Strikingly, said Lord Goff, a comparable principle had developed which limited liability under the rule in *Rylands v Fletcher*. This was the principle of 'natural use' of the land. The unnatural use arose when that use involved increased danger to others. Then the defendant would be liable for the harm suffered by the plaintiff, notwithstanding that he has exercised all reasonable care and skill to prevent the escape from occurring.

The liability in nuisance is strict, but subject to the principle of 'reasonable user'. But it by no means followed, said Lord Goff, that the defendant should be held liable for damage of a type which he could not reasonably foresee; and the development of the law of negligence in the past sixty years points strongly towards a requirement that such foreseeability should be a prerequisite of liability in damages for nuisance, as it is of liability in negligence. Foreseeability was an essential element in determining liability in public nuisance for the spill of oil in Sydney Harbour.[15] In Lord Goff's judgment, the law was settled to the effect that foreseeability of harm is indeed a prerequisite of the recovery of damages in private nuisance, as in the case of public nuisance.

Lord Goff turned to consider the matter of foreseeability as an element in liability under ***Rylands*** *v Fletcher*. The general tenor of Blackburn J's statement of principle was that knowledge of the risk, or at least foreseeability of the risk, is a prerequisite of the recovery of damages under the ***Rylands*** principle. But the ***Rylands*** principle is one of strict liability in the sense that the defendant may be held liable notwithstanding that he has exercised all due care to prevent the escape from occurring. Lord Goff concluded that the historical connection of ***Rylands*** liability with the law of nuisance must now be regarded as pointing towards the conclusion that foreseeability of damage is a prerequisite of the recovery of damages under the ***Rylands v Fletcher*** rule. The recovery of damages in private nuisance depended on foreseeability by the defendant of the relevant type of damage. It was logical to extend the same requirement to liability under the rule in ***Rylands v Fletcher.***

Should ***Rylands*** be developed by the courts as a principle of strict liability for damage caused by ultra-hazardous operations, on the basis of which persons conducting such operations might properly be held strictly liable for the extraordinary risk to others involved? The cost of such damage would then be absorbed as an overhead of those engaged in the hazardous activity, rather than impose it on the injured person, its insurers or the wider community. This appeared to Lord Goff to be the trend in the USA.[16] But as a general rule, it was more appropriate in His Lordship's view for strict liability in respect of operations of high risk to be imposed by Parliament, not by the courts. If such liability is imposed by statute, the relevant activities can be identified, and those concerned can know where they stand. Furthermore, he added, statute can where appropriate lay down precise criteria establishing the incidence and scope of such liability.

Returning to the instant case, all the ingredients were present to hold ECL liable in nuisance and under the principle of ***Rylands.*** But when ECL created the conditions which have ultimately led to the present state of affairs-whether by bringing the PCE in question on to its land, or by retaining it there, or by using it in its tanning process—it could not possibly have foreseen that damage of the type now complained of might be caused thereby. Indeed, long before the relevant legislation came into force, the PCE had become irretrievably lost in the ground below. In such circumstances, Lord Goff did not consider that ECL should be under any greater liability than that imposed for negligence.

His Lordship added that the present case might be regarded as one of historic pollution, in the sense that the relevant occurrence (the seepage of PCE through the floor of ECL's premises) took place before the relevant legislation came into force; and it appeared that, under the current philosophy, it was not envisaged that statutory liability should be imposed for historic pollution. If so, said Lord Goff, it would be strange if liability for such pollution should arise under a principle of common law. Since those responsible at ECL could not at the relevant time reasonably have foreseen that the damage in question might occur, the claim of CWC for damages under the rule in *Rylands v Fletcher* failed.

3 Conclusion

The common law controls on the developer who causes deterioration in the neighbourhood's environment are found to be less than adequate to afford the degree of protection generally required. Negligence requires proof of fault which is difficult to establish. Both nuisance and *Rylands* liability are said to be 'strict' and independent of fault, but require foreseeability of damage caused as a prerequisite to liability, and that so-called 'strict' liability is subject to relaxations—that of 'reasonable user' in nuisance cases, and that of 'natural use' of land in *Rylands v Fletcher* cases. Legal standing to sue in nuisance exists only for the person with exclusive right to possession of the affected property. A mere licensee has no such right. Society beyond the adjacent landowner had better look to statutory regulation for protection from, and sanctions against environmental deterioration. Developers need fear little in the common law beyond the immediate adjacent landowner. Only sanctions in criminal law pose any substantial risks.

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1 (1868) LR 3 HL 330; [1861-1873] All ER Rep 1. The case name became the principle's label.

2. Paraphrased words of Lord Atkin in *Donoghue v Stevenson* [1932] All ER Rep 1, 11G-H.

3. Two joined cases. [1997] 2 All ER 426 (HL).

4. Using special powers under the Local Government, Planning and Land Act 1980, designed to encourage the regeneration of such rundown areas.

5. The London Docklands Development Corporation, formed by an 1980 Order which designated London's docklands an urban development area.

6. Under the Town and Country Planning Act 1971.

7. [1997] 2 All ER 426, 447d-e.

8. See Lord Simonds in *Read v J Lyons & Co Ltd* [194612 All ER 47 1,482.

9. *Motherwell* v *Motherwell* (1976) 73 DLR (3d) 62. Now of doubtful authority.

10. *Khorasandjian* v *Bush* [1993] 3 All ER 669. Overruled insofar as it holds that a mere licensee can sue in private nuisance (Lord Goff at 441b).

11. The American Law Institute's *Restatement of the Law* of *Torts* (2 ed) 1977 which echoes *Prosser and Keeton on Torts* (5 ed) 1984: pp.621–622, cited at [1997] 2 All ER 426,460.

12. 419 SE (2d) 661 (1992).

13. [1994] 1 All ER 53 (HL).

14. (1885) 29 Ch D 115.

15. *The Wagon Mound (No 2), Overseas Tankship (UK) Ltd v Miller Steamship Co Pty Ltd* [1967]1 AC 617; [1966] 2 All ER 709 (PC).

16. *See* § 519 of the *Restatement of Torts* (2d) vol 3 (1977).

Construction Projects: the Culture of Joint Venturing

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Abstract
This paper considers the diversity of project procurement approaches which exist in most countries' construction industries as, essentially, a spectrum of joint venture arrangements. In striving for performance improvement, the underlying objective is considered to be participant satisfaction, subject to a power hierarchy. Participant goals are critical in determination of goals for a project; these are subject to major cultural influences in both their determination and communication. Transaction costs are employed to consider the costs of forming and pursuing relationships between project participants; such governance costs are supplemental to the neo-classical production costs. It is concluded that cultural considerations are vital to development of accepted project goals and that such goals are critical in obtaining efficient and effective performance to secure participant satisfaction.
Keywords: Culture, goals, joint ventures, participant satisfaction, procurement, transaction costs.

1. Introduction

The issue of selecting the most appropriate method of procuring a construction project remains a fundamental decision for both clients and members of the construction industry. Much effort has been and remains devoted to quantifiying differentations between procurement 'systems', often to the exclusion of examination of commonalities and the elicitation of participants' requirements - both criteria and parameters. Ireland [1] alluded to the potential fallacy of extensive procurement system differentiation.

In essence, all procurement approaches involve some form of joint venture - from the often individual (organisation) orientation of the fragmented, 'traditional' TMO (temporary multi organisation) approach [2] to the collaborative formalities of integrated procurement - notably the BOT 'family', partnering and formalised joints ventures.

In tandem with analyses of performances of, especially major, projects, there are suggestions that critical success factors (CSFs) may exist. Unfortunately, there appears to be considerable oversight of assumptions inherent in CSF analyses, most notably that success depends on circumstances, perspective and goals. What may be successful for one project participant may be a disaster for another! Further, while success concerns a (comparative) evolution of performance, it is likely that a more fundamental variable is participant satisfaction - performance as perceived by the participant under examination.

Thus, the organisational processes of project procurement (a managerial 'how'?) constitute a medium - an intervening, contextual variable - for performance achievement and goal realisation.

2. Procurement

Procurement choice requires analysis of three dimensional matrix and, although a set of decision phases which occur at discrete times of a project in practice, preferably should be evaluated holistically at project conception/inception. However, a significant inhibitor is the (lack of) development of project (performance) goals.

The main dimensions of the matrix array project participants, participant relationships and project performance variables. It is helpful to adopt a functional approach in drawing up the matrix and proceeding with its evaluation [3]. Clearly, the earlier the evaluation occurs the greater is its potential effectiveness.

Procurement may be viewed from a systems perspective as involving a chain of client, design and construction functions. Environmental controls are moving variably in UK - the well-known vagaries of politics, economics and social factors - but with 'technical' controls of 'town planning', 'building control' and 'environmental control' moving differentially (e.g. more flexible building control but increasing anti-pollution and safety regulations); reflecting almost global trends which commenced in the late 1970s.

In UK and similar societies, much analysis of procurement has focused on selection of the main contractor. Although published clients' guides to procurement - e.g. [4] incorporate selection of designers as well as constructors, their assumptions of applicable performance criteria are rather confused and so, may detract from the determination of more appropriate criteria for individual projects. Further, by concentrating on criteria, attention to parameters and to value management possibilities may diminish.

Thus, procurement brings together technical project performance possibilities, (interpreted) legislative requirements of the project environment with the human-based (for major projects) organisational requirements and the personal characteristics of the decision takers within their evolving power structure(s). Economic, political, social etc. factors become internalised in project decisions by their impacts on criteria and parameters, thereby constituting constraints on subsequent decisions and actions.

3. Joint Ventures

Joint ventures are ‘characterised by oligopolistic partners’ [5]. In construction, formal joint venturing is increasingly common on major, especially international, projects.. In developing countries, many major projects are aid funded (directly by project finance or indirectly via country finance, the latter being preferred by the world bank etc.) which may involve ‘tie-backs’ to donor countries; involvement of local organisations - many nations require local involvement via joint venturing to promote ‘technology transfer’ - extends the scope of joint venture arrangements and adds a further dimension to the joint venture decision by the overseas partner(s). In the absence of a requirement for joint venturing, joint ventures occur as amalgamations of participants due to project size or technologies, translatable into risk perceptions and resourcing requirements.

Formal joint ventures may be project-based or ‘strategic’, i.e. formed for a particular project only or established as a continuing association of the participants; project joint ventures tend to be more opportunistic and relatively casual in their establishment - whereas a strategic joint venture is likely to be a separate company under the ownership of the joint venturers. Thus, the linkages between even formal joint venture participants are of differing degrees of permanence and legal relationship constructs.

Widely, construction projects are portrayed as team efforts, implying thereby significant components of joint venturing. However, all but formal joint venture procurement arrangements involve a complexity of buyer-seller relationships concerning the provision of design and construction services and products through direct and sub contracting relationships. Thus, the purported team identity has been characterised more appropriately as a TMO or coalition [6].

In order for a teamwork situation to exist on a project, there must be a goal or set of goals which are acceptable to the project participants. Given such knowledge, risk apportionment can be developed appropriately and explicitly such that the accepted (via contracts entered) performance requirements are not used merely as a basis to secure work and from which return enhancements are sought rigorously (claims etc.). Whilst it is clear that current work allocation and contract mechanisms, via ‘tender’ and contract terms, set out performance requirements explicitly in return for the price bid (acknowledging permissible adjustments), there is no evidence, anecdotal or otherwise, that such requirements are derived from and compatible with project goals.

4. Goals (and parameters)

‘Prospective partners should have a clear understanding of one another’s goals and objectives in establishing a joint venture. While different parties will invariably have different objectives, these must not be contradictory. It is important therefore, that the priority goals of each party be specified and be understood by all partners from the outset' [7].

Many researchers view organisations as goal oriented, social conglomerates e.g. [8], [9]. The perspective is reinforced by others who regard organisations as systems which co-ordinate people and other resources to achieve performance goals [10], [11]. Porter [12] asserts that goals must be defined in order to focus 'the attention of individuals and groups (and) to provide a source of legitimacy for decisions!

Perrow [13] distinguishes official and operative organisational goals (analogous to the formal and informal project operational systems [14], [15], whilst Pervin [16] notes that goals are arranged in a (flexible) hierarchy. However, importances of goals in a hierarchy change with alterations in organisational power distributions. Managing organisational goals is a continuous process in which 'competing and conflicting priorities must be balanced' [17]. Thus, a hierarchical set of (project) goals is likely to be unstable due to the constantly varying power structure of construction TMOs.

Satisficing may be a necessary approach to achieving performance on multiple goal projects [18] (especially if some goals are mutually exclusive, if only in a maximising sense) however, overt satisficing may detract from higher levels of performance which a bounded competitive maximising approach by project participants could (otherwise) achieve. It is important to preserve the incentive facets of goals.

Organisations consist of groups which comprise individuals. The amalgamation of a number of discrete organisations into a TMO fosters exponential expansion of organisational and, hence, goal (determination and achievement) complexities. Generally, individuals relate to organisations as members of groups and, hence, are subject to particular cultural influences and influences through sentience etc. Thus, the interactions and interdependencies, between a project TMO and the individuals working in it are filtered through the discrete organisations and groups [11], [19], [20]. Such effects are reinforced by indexicality (meanings/understandings being dependent upon socialisation, education, training etc.) and rules/codes as well as norms of behaviour for the variety of professional and other groupings [21].

Goals impact on both product and process - on product in determining what is sought and, thence, demanded; on process by influencing performance in supplying the product (project outputs). Peoples' behaviours are determined by goals, self-efficacy (their perceived performance capabilities) and motivation, stimulated by the organisation's expectations and subject to situational constraints [22]. Behaviour can be examined as a vector, having magnitude and direction, which has both cognitive (thought process; 'rationality') and affective (emotion) components [23].

Four major determinants which related goals to performance outcomes:

- legitimate authority of the goal setter
- peer and group pressures towards goal commitment
- participants' expectations (that effort leads to performance)
- incentives and rewards (to enhance commitment to goals) [24].

Naturally, communication of goals is essential if the goals are to operate for performance achievement.

A particular issue for construction is not only the identification of participants' goals but their combination to yield project goals. For UK building projects, not only are most clients poor in providing briefing information (understandable, as most clients are 'naive') but architects are poor at obtaining the information necessary for a good project brief from clients [25]. Further, '..the tradition persists whereby the architect prepares a sketch plan from which the other consultants work. Frequently alone and, often, in a matter of hours, the architect arranges spaces in a structure using predominantly aesthetic criteria' [26].

Thus, the determination of, even, client goals regarding projects is questionable. Designers have a vital but difficult task of determining the clients needs (which may involve identifying the client(s)) usually expressed in terms of the client's business and translating those needs into a design, likely to meet those needs, compatible with design inputs of other designers and realisable by the constructors; all within parameters set by (or agreed with) the client and regulating authorities!

Clearly, early involvement of primary participants will reduce the need to forecast (rationally assume) those organisations' individual goals and facilitate agreement of realisable project goals with acceptable degrees of (in)compatibility. In practice, project participant involvement is staged progressively and design proceeds iteratively to yield progressive fixing of goals and setting (conversion of criteria into) parameters (e.g. specification, total project cost, duration) which are imposed on following participants' inputs or, if essential, changed with difficulty and costs.

5. Culture

Culture has been defined in a vast number of ways - from 'the way we do things' to the dimensioning of, 'The collective programming of the mind which distinguishes one group from another', using four dimensions; consideration of organisational cultures employs six dimensions [27]. Further, how culture is regarded, and, hence, may be 'employed' falls into two main arenas - as a 'tool' or as a 'method'; Smircich [28] echoes the dichotomy for organisational cultures - as something which an organisation has or something which an organisation is.

Human behaviours - individual and various levels of collective - suggest that the cultural groupings and strata (organisations, professions, etc.) are likely to be self perpetuating. The difficulties of changing beliefs, an underpinning of behaviours, indicate that changes will be peripheral and slow to occur. Cultural indicators – symbols (notably, language), icons/heroes, behaviours etc. can be observed to suggest the underpinning beliefs which are ordered into a hierarchical value structure; an obvious problem is the 'cultural colouring' imposed by the observer and the research instrument(s) employed.

Construction organisations to be flexible in order that they survive and be successful [29]. The informal system – used for project operation – is highly adaptive with participants bringing their knowledge and experience to assist the interpretation of the formal system's constituents [14],[15]. For UK, 'The culture of the industry has been evolved by members in order to deal with its economic reality. Any attempt to change culture, which does not also tackle the problems which gave rise to it, stands little chance of success' [30]. Clearly, the 'technological' sub-systems are subjugated to the economic system such that 'business imperatives' operate.

6. Transaction costs

Transaction costs comprise, 'the running costs of the economic system', [31] and, as such, constitute various elements of friction in an economy. They may be classified as *ex ante* and ex *post* agreements (via contracts) 'governing' the transaction(s) in question [32]; *ex ante* costs are those pertaining to drafting, negotiating and safeguarding relationships, whilst *ex post* costs involve costs of post contract problems (what occurs is at variance with what the drafters intended) and their rectification (however achieved – including arbitration and litigation) and the cost of bonds etc. required in attempting to make the agreement (assurance of having obligations fulfilled) more secure. Clearly, the two categories of transaction costs are interdependent - normally, an inverse relationship.

Ownership of real property involves not only rights to primary (ownership) title but, in general forms, use rights, appropriation of returns rights and alteration rights. In terms of construction supply, (normally) the suppliers are given use and adaptation rights by the primary owner in return for a pre-determined sum. However, in arranging the supply mechanism, distributions of appropriation rights in recompense for use rights and adaptation duties form the focii of transactions; in establishing distributions of such rights and duties, bargaining is widespread but within various power paradigms [33] and subject to bounded rationality [18].

Hence, agreements are reached and, logically, are intended to deal with perceptions of participant objectives and behaviours and environmental influences under conditions of uncertainty. Therefore, the objectives of *ex_ante* actions are to predict and control, within the objectives of the particular organisation (short term/ long term) the *ex* post situation – notably expected costs and returns.

Most commonly, economic analyses focus on profit maximisation or, given a price (such as consequent upon tendering), cost minimisation. Adopting an holistic view of the provision of a good or service (e.g.. a construction project), the objective involves minimisation of both production and transaction cost. Benefits (e.g. price reduction) of large number *ex ante* competition are likely to be eroded by *ex post* 'quasi monopoly'.

Standard form contracts and 'normal' procurement arrangements have evolved reactively in construction; use of off-the-shelf *ex ante* documents etc. may reduce both cost categories but increasing adaptation of standard forms, notorious *ex post* opportunisms and new procurement approaches testify to difficulties [34], [35].

Increasing attention to value chain approaches in construction, attention to clients' perceptions of value and realisation of equal technical abilities amongst pre-selected suppliers and recognising interactions of 'process efficiency' and "product effectiveness' shows the importance of transaction costs in determining appropriate organisational structuring via considerations of (inter-) organisational governance.

'. . . as transactions become more idiosyncratic.. vertical integration will . . appear ..' [32]. Although, in construction, almost all projects are bespoke and operate under joint venture characteristics, indiosyncratic projects can be seen as involving exceptional risks (size, finance, location, technology etc.; individually but usually, in combination). Often, such idiosyncratic projects are undertaken by formal joint ventures. Formal joint ventures may be required by a host country to assist its development. Normally, only size factors induce horizontally combinations, the remainder involve vertical combinations – including the informal joint venturing of most construction projects.

7. Conclusions

The widespread striving for increasing efficiency and effectiveness of construction projects, most obviously by enhancement of common measures of project performance (in terms of time, cost and quality), can be secured only by attention to transaction costs as well as production costs. In tuning governance structures to facilitate holistic economies, attention must be paid to behavioural factors – the essence of cultural analysis.

Attention should be devoted to determining and communicating appropriate and acceptable project goals which should accord with performance criteria ancl parameters of the project and evolved to be compatible with goals of project participants. Only in such circumstances can holistic costs be minimised, taking account of cultural factors involved – notably those pertaining to bargains and relationships, including individual transaction versus long term perspectives.

Particpants' views of value are critical (exchange and use values). Consideration of costs alone – even if holistic and aimed at reduction – can provide partial analysis only.

8. References

1. Ireland V., (1984) Virtually Meaningless Distinctions between Nominally Different Procurement Forms, *Proceedings 4th International Symposium on Organisation and Management of Construction.* Waterloo, Canada. Vol. 1 pp 203-212.
2. Cherns A. B., Bryant D. T. (1984) Studying the Client's role in construction management, *Construction Management and Economics,* Vol. 2, pp 128- 144.
3. Jaggar D., Rowlinson S .M., (1994) Co-ordinators' oral introduction, *Proceedings CIB W-92 Symposium, East Meets West,* Hong Kong, Dec.
4. Building Economic Development Council (1984) *Thinking about Building,* London, HMSO.
5. Dietrich M., (1994) *Transaction Cost Economics and Beyond,* London, Routledge.
6. Fellows R. F., Langford D. A., Newcombe R., Urry S. A. (1983) *Construction Management in Practice,* Harlow, Longmans.
7. *U.N.* (1988) *Joint Ventures as a Form of International Economic Co-operation,* United Nations Centre on Transnational Corporations, New York, United Nations.
8. Parsons T. (1956) Suggestions for a sociological approach to the theory of organisations I and II, *Administrative Science Quarterly,* Vol. 1 pp 63-85; 225-239.
9. Georgiou P. (1973) The Goal Paradigm and notes towards a counter paradigm, *Administrative Science Quarterly,* Vol. 18, pp 29 1-3 10.
10. Robbins S. R. (1983) *Organisational Theory: the structure and design of organisations,* Englewood Cliffs, Prentice Hall.
11. Miner J. B. (1988) *Organisational Behavior: performance and productivity, New* York, Random House Business Division.

12. Porter L. W., Lawler E. E., Hackman J. R. (1975) *Behaviour in Organisations,* New York, McGraw Hill.
13. Perrow C. (1961) The Analysis of Goals in Complex Organisations, *American Sociological Review,* Vol. 26, no. 6, Dec.
14. Higgin G., Jessop N. (1965) *Communications in the building industry,* London, Tavistock.
15. Higgin G., Jessop N., Bryant D. T., Luckman J., Stringer J. (1966) *Interdependence and Uncertainty,* London, Tavistock.
16. Pervin L. A. (1989) Goal Concepts; themes issues and questions, in Pervin L. A. (ed.) *Goal Concepts in Personality and Social Psychology,* Lawrence Erlbaum Associates.
17. Donaldson G. (1985) Financial Goal and Strategic Consequences, *Harvard Business Review,* Vol. 6, no. 3, pp 57-66.
18. Simon H. A. (1960) *The New Science of Management Decision,* Harper and Row.
19. Gibson J. L., Ivancevich J. M., Donnelly J. H. (1982) *Organisations: behavior, structure, process,* Plano Business Publications.
20. Szilagyi A. D., Wallace M. J. (1983) *Organisational behavior and performance,* Glenview Scott Foresman.
21. Clegg S. R. (1992) Contracts cause conflicts, in Fenn P., Gameson R. (ed.) *Construction Conflict Management and Resolution,* London E & FN Spon.
22. Liu A. M. M. (1995) *Evaluation of the Outcome of Construction Projects,* PhD Thesis (unpublished), The University of Hong Kong.
23. Naylor J., Pritchard R. D., Ilgen D. R. (1980) A *Theory of Behavior in Organisations,* New York, Academic Press.
24. Locke E. A., Latham G. P., Erez M. (1988) The determinants of goal commitment, *Academy of Management Review,* Vol. 13 pp 23 -29.
25. Mackinder M., Marvin H. (1982) *Design Decision Making in Architectural Practice,* Institute of Advanced Architectural Studies, Research Paper 19, University of York.
26. Lera S. (1982) At the Point of Decision, *Building,* 28 May pp 47-48.
27. Hofstede G. (1994) *Cultures and Organisations,* London, Harper Collins
28. Smircich L. (1983) Concepts of culture and organisational analysis, *Administrative Science Quarterly,* Vol. 28, pp 339-358.
29. Lansley P., Quince T., Lea E. (1979), *Flexibility and Efficiency in Construction Management,* Ashridge Management Research Unit.
30. Seymour D. E., Rooke J.A., (1995) The culture of the industry and the culture of research, *Construction Management and Economics,* Vol. 13, No. 6, pp5 1 l-523.
31. Arrow K. J. (1969) Toward a theory of price adjustment, in Abramoritz M. et al (ed.), *The Allocation of Resources,* Stanford, Ca., Stanford University Press.
32. Williamson 0. E. (1985) *The Economic Institutions of Capitalism,* New York, The Free Press.
33. Newcombe R. (1994) Procurement Paths-a power paradigm, *Proceedings, CIB* W-92 *Symposium, East Meets West,* Hong Kong, Dec., pp243-250.
34. Latham Sir M. (1994), *Constructing the Team,* London HMSO.
35. *Bennett* J., Jayes *S.* (1995) *Trusting the Team,* Reading Construction Forum, Centre for Strategic Studies in Construction, University of Reading.

Dispute Review Boards 1998: The Need to Stay on Track

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Abstract
A 1992-94 Construction Industry Institute (CII) study identified the elements deemed essential for a successful dispute review board (DRB). These finding and recommendations were reaffirmed in the Construction Dispute Review Board Manual, published in 1996. In the interim period, the use of DRB's has continued to increase, both in the U.S. and other countries. This trend is expected to continue. At the same time a variety of practices inconsistent with the recognized published norms have emerged. Some Employers/Owners--and some DRB members--apparently feel compelled to "tinker" with a well established process, contrary to the maxim of "If it is not broken, don't fix it." An example with potentially widespread implications is the World Bank required modification to FIDIC Red Book Clause 67, which has unrealistic timelines and compensation provisions. Problem areas emanating from other clauses and on a variety of projects include neutrality of DRB members, proposals for reducing the frequency of site visits, attempts to limit the jurisdiction of DRB's, long and complex pre-DRB procedures, a trend towards formal adversarial hearings, and unnecessarily long DRB recommendations. It is essential that all involved in the DRB process--specifier, employer/owner, and contractor--work to help ensure that the process is not so diluted, modified, or corrupted as to adversely impact its effectiveness. Otherwise, the resolution rate (over 99%) and attractiveness will markedly decline, which would be detrimental to the construction industry. This paper will identify the problems and propose solutions.
Keywords: Dispute Resolution, Dispute Review Boards.

1 Introduction

Variations from proven Dispute Review Board (DRB) practices may degrade the process and dilute its effectiveness. This paper reviews the characteristics widely deemed to be important for successful DRB usage. It then identifies some of the anomalies and variations that have been introduced and explains why the deviations from accepted practice should be avoided. The purpose of the paper is to encourage adherence to the norm and discourage unwarranted "tinkering."

2 Background

The Dispute Review Board, sometimes termed a Dispute Resolution Board (or Panel) or Dispute Adjudication Board, is a well established method of jobsite level construction dispute resolution. It has been used on several hundred contracts. Increased use is projected.

The essential and fundamental concepts of a Dispute Review Board are:

1. A panel of three impartial mutually-selected/approved individuals with expertise appropriate to the project, established at the beginning of construction.
2. Periodic site visits by the Board, including meetings with representatives of the parties.
3. Informal on-site hearings conducted by the Board, during which it considers documentation and oral statements/arguments of the parties relative to a particular dispute.
4. A written non-binding recommendation from the Board to the parties for resolution of the dispute.

The DRB is an alternative dispute resolution process that has been shown to provide four clear benefits:

1. Early attention to and informed objective evaluation of issues arising during contract performance. This provides a "reality check" on the parties' positions.
2. Prevention of some disputes and prompt business-like resolution of other disputes on an individual basis before they grow into larger problems or accumulate.
3. Cost effectiveness.
4. Facilitation/encouragement of cooperation between on-site managers for the Employer and the Contractor.

2.1 Generally

As the process name suggests, the purpose of a DRB is to <u>review</u> disputes after bilateral negotiations have reached an impasse. Such review takes place as early as possible after impasse is reached at the jobsite level. DRB involvement often follows a formal decision by an owner/employer designee such as an architect, engineer, or construction manager. The DRB's output is a written recommendation, normally non-binding. The

Board, which usually is comprised of individuals from several disciplines relevant to the project, obtains input for its recommendations from four basic sources:

- Project knowledge gained through periodic site visits and periodic informal on-site progress discussions with the parties.
- Receipt and review of job and progress meeting minutes.
- Prehearing statements of position on specific disputes.
- Informal hearings, usually held at the jobsite, with individuals having first-hand knowledge of the facts relative to the dispute and where copies of documents are provided to the Board.

The reported resolution rate of disputes submitted to DRB's exceeds 99 percent. Any action that modifies the flow of information can be detrimental.

2.2 Applications

The first generally recognized deployment of a DRB was for the second bore of the Eisenhower Tunnel in 1975.[1] For the next 10 to 12 years, major growth took place in the heavy and underground construction industry. Subsequently, it has been endorsed for -- and found widespread acceptance in -- building and process construction as well.[2] Currently the DRB has been used on heavy, underground, other civil, process, and building construction contracts in both the private and public sectors.

A sizable fraction of total DRB usage has been on projects under US$ 10 million, and over half of the DRB projects had a cost of less than US$50 million. Because a DRB provides a tangible but somewhat nonquantifiable benefit to any project, making this decision based on cost becomes essentially a subjective cost-benefit analysis. The cost of a DRB can be on the order of US$5,000-10,000 per meeting day. Assuming quarterly meetings of one to two days in length, the annual cost becomes US$20,000-80,000. Thus, on a US$lO million contract, the costs for DRB operations, exclusive of the involvement of the participants from the owner and the contractor, is 0.2-0.8% of contract price. Many consider this a very cost-effective investment, particularly when compared to the costs of arbitration and litigation.

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1. Matyas, R.M., Mathews, A.A., Smith, R.J. and Sperry, P.E. (1996) *Construction Dispute Review Board Manual,* McGraw-Hill.
2. In 1990, the Construction Industry Institute Dispute Prevention and Resolution Task Force undertook a study of the DRB process, which resulted in the publication of research results in 1992. Vorster, Michael C. *Dispute Prevention and Resolution: Alternative Dispute Resolution in Construction with Emphasis on Dispute Review Boards,* Construction Industry Institute, 1992.

3 Essential elements

In an extensive, multi-year empirical study of the DRB process supported by the Construction Industry Institute[3], Professor Michael C. Vorster of the Civil Engineering Department of Virginia Polytechnic Institute and State University and the CII Dispute Prevention and Resolution Task Force studied numerous Dispute Review Boards in action and additionally reviewed a variety of DRB contract provisions. This resulted in publication of a "Classic DRB Methodology Checklist." The components of this checklist are shown in the left hand column of Table 1. Explanatory comments and opinions of the author concerning the significance or practical application of these items are in column 2.

4 Observed deviations from recommended practices

Column 3 of Table 1 notes those features which have been observed to have been modified or not used at all.

5 Comments and recommendations on deviations

Column 4 of Table 1 briefly describes the anomalies and deviations and notes the considerations involved.

6 Other detrimental practices

6.1 Rigid time line

To be sure, prompt processing of disputes is important. However, some contract provisions, e.g., the World Bank's alternate to FIDIC Red Book Clause 67 has rigid limits. The DRB must schedule, convene and hold a hearing and issue its recommendation within 56 days of a request. Sometimes this is not practical or workable.

6.2 Jurisdictional limitations

Occasionally, a DRB specification will be written to limit the Board's jurisdiction. One such specification limited the DRB to only issues arising under the technical specifications. This is not prudent, for it may lead to disputes over jurisdiction.

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3. A consortium of U.S. contractors, owners, engineers and universities.

7 Conclusion

While the deviations from the model that have been observed may be well-intentioned, there has been no showing that they are justified. Indeed, for the reasons stated in the table, these variations can be detrimental and should be avoided.

TABLE 1
CLASSIC DRB METHODOLOGY CHECKLIST
(AS DEVELOPED BY PROFESSOR M.C. VORSTER, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY, WITH 1998 COMMENTARY BY ROBERT J. SMITH)

"You may use this checklist to assess the compliance of a particular DRB with the classic methodology developed by UTRC [the ASCE Model]. There should be a positive response to all 22 statements."

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
CONTRACT REQUIREMENTS			
1. The intention to establish a Board is noted in the instructions to bidders.	This generally indicates an enlightened owner and is thought to encourage lower bids.	No	None
2. The provisions for establishing the Board are set out in the contract.	This enables both parties to understand their rights and responsibilities with respect to setting up the DRB, and usually requires early establishment.	No	It is of course possible to amend an existing contract to add a DRB

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
3. The provisions for establishing the Board do not preclude either the owner or the contractor from resorting to other methods for the final settlement of disputes.	In other words, the DRB output is not final or binding; no rights are surrendered.	No	Sometimes completion of the DRB process is a prerequisite to more formal or binding resolution.
MEMBER QUALIFICATIONS			
4. Board members are neutral, able to serve owner and contractor equally and have no conflict of interest.	This is critical to success.	Yes	Owners and Contractors sometimes nominate individuals with a known general tendency to favor their position. In addition, some members seem to be nominated only by Contractors. Further, when confronted with disputes, some DRB members take a results-oriented view which can lead to 2 to 1 recommendations, which are much less influential. It is recommended that reference checks and rigorous screening of nominees be undertaken.
5. Board members have acknowledged technical expertise in the type of work being undertaken.	This promotes **(1)** confidence that the Board members understand the facts, issues, and contract requirements, and (2) efficiency.	No	An effort should be made to select individuals with appropriate discipline experience.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
6. Board members are respected by the owner and contractor for their impartiality and technical expertise.	This is critical to success; the mutual evaluation, selection, and appointment process assures this.	Yes	See comments for Item 4 above.
MEMBER SELECTION			
7. Owner and contractor have each nominated one Board member. These two members have selected the third member to act as chairperson of the Board.	This permits each party to "hand-pick" one neutral, subject to conflict of interest requirements and the other party's approval.	Yes	An acceptable alternative is for the Owner and Contractor to each offer a slate of three candidates acceptable to it, from which the other party may select one.
8. All parties agree on the selection and appointment of all Board members.	"Hands on" involvement in the process promotes confidence. This requirement tends to discourage a party from nominating one who might be perceived as an advocate. Rarely if ever is a nominee rejected, and then only for verv valid reasons.	No	None

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
OPERATING PROCEDURES			
9. Board members receive regular, written progress reports and remain informed on the status of the work.	These need not be special reports. Typically, the periodic (weekly or monthly) progress reports and progress meeting minutes which are prepared in the regular course of contract administration are quite satisfactory. The time required for Board members to review such reports is modest and not of significance from a fee perspective.	**No**	Occasionally the reports are received long after their initial issuance.
10. Board meetings are held on the job site at regular intervals, not exceeding four months.	This is critical, and the temptation to postpone or cancel meetings because there are no pending disputes should be resisted. This would be false economy, and deprive the DRB of the opportunity to continue to build familiarity with the project and its participants.	**Yes**	In an apparent effort to economize, the contract parties sometimes increase the interval between meetings to six months or more, or put the DRB in an "on-call" status. This is inadvisable. The DRB is deprived of the opportunity to develop an understanding of the project as well as the opportunity to develop rapport and mutual respect between it and the contracting parties, and vice versa.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
11. Presentations to the Board are made by field project managers who are completely involved in the process.	First hand accounts are valuable.	Yes	Claiming parties will occasionally seek to have representation or participation by lawyers or consultants. With limited exceptions this should be discouraged. It almost necessarily results in the other party wanting to have the same level of outside assistance. This adds to the time and cost and gets away from the fundamental concept of the board considering disputes as they develop in the field.
CONDUCT OF HEARINGS			
12. Either owner or contractor is able to appeal any decision, action, order, claim, or controversy to the Board at any time.	It is presumed that good faith bilateral negotiations have been conducted. However, the practice of some owners of interposing numerous procedural prerequisites or levels of review before going to the DRB diminishes many of the advantages of the DRB.	Yes	Some contracts unfortunately have a protracted process before an architect or engineer decision. This becomes a barrier and should be avoided.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
13. Both owner and contractor are adequately represented at all hearings; rebuttal and requests for clarification are permitted.	Adequate representation refers to "key players," not counsel. Experience has shown that principals know when they have said enough.	No	None
14. Board recommendations are in writing and are made directly to the project participants who are responsible for accepting, appealing or rejecting recommendations.	The written recommendation with rationale demonstrates the DRB's understanding of the dispute. The rationale/explanation helps persuade the disappointed party to accept the recommendation.	No	None
TIMING AND SEQUENCE OF EVENTS			
15. Board selection and appointment is made within eight weeks of notice to proceed with contract work.	Having the DRB in place early permits it to become acquainted with the project and its participants. Having it in place before disputes are likely to arise prevents posturing or vacillation regarding the process.	Yes	The delay in getting the board organized is perhaps the most frequently observed problem. Often it seems that it is the owner that is not prepared to act expeditiously. One method for combating this is for the owner to have a pre-qualified list of candidates available before contract award.
16. Appeals are made to the Board as soon as possible and the Board handles issues current at the time of appeal.	The "real-time" component promotes prevention and item-by-item resolution.	Yes	See comments for number 12 above.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
17. Written recommendations of the Board and the reasoning supporting the recommendations are made available to the project participants within two weeks of an appeal.	Two weeks is desirable, but occasionally difficult to achieve. On the other hand, some recommendations can be issued in a matter of hours or days.	Yes	Two weeks is sometimes but not always possible. The parties should perhaps continue to use it is a guideline but recognize that exceptions will need to be made. Applying it rigidly could deprive the board of necessary analysis time.
LIMITATIONS OF AUTHORITY			
18. Board members do not act as consultants and do not give advice on the conduct of the work.	To do so would obviously compromise neutrality.	No	None
19. The Board does not usurp either the owner's or the contractor's authority to direct the work as provided in the contract.	The DRB's role is to (1) review and (2) make recommendations for resolution of disputes presented to it.	No	None
SUBSEQUENT PROCEEDINGS			
20. The recommendations of the Board are not binding and may be rejected by either owner or contractor.	This promotes focus on the most relevant evidence and facilitates informal procedures.	Yes	Occasionally DRB specifications are written so that the recommendation will be binding. This tends to increase the formality, length, and cost of hearings. Careful consideration should be given before this adopted.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
2 1. The written recommendations of the Board and the reasoning supporting the recommendations are admissible as evidence in any subsequent dispute resolution procedure.	This is a very controversial issue with meritorious arguments on both sides.	Yes	This is perhaps the most frequently discussed and modified term in DRB specification. On the one hand, it is acknowledged the recommendation should be persuasive to a an adjudicatory body, such as a court or arbitration panel. On the other hand, there is a legitimate concern that DRB findings, typically based on unsworn testimony and hearsay that would not be admissible in a formal legal proceeding can be brought in through the "back door." The specification recommended in the Construction Dispute Review Board Manual permits admissibility of (1) the fact that there was a DRB; (2) the identities of the DRB members; and (3) the ultimate recommendation be admitted. In a sense this is akin to an expert witness opinion. Other DRB specifications say that the DRB output is admissible within the discretion of the adjudicatory body.

Vorster Checklist Item	Smith Comment/ Opinion	Deviations/ Anomalies	Comments Noted by Smith and Smith Recommendations
COSTS			
22. The cost of the Board is borne equally by the owner and the contractor.	This is consistent with the notion of the DRB being a neutral panel.	No	None

Appendix -- References

Carr, F.; Rubin, R. A.; and Smith, R. J. 1992. "Dispute Review Boards," Chapter 5 in 1992 *Wiley Construction Law Update*, Currie and Sweeney, eds.

Center for Public Resource, Inc. (CPR). 1991. *Preventing and Resolving Construction Disputes.* CPR.

Dispute Review Board Foundation, 1997. *Tabulation of Dispute Review Boards*

Groton, J. P. 1993. Dispute Review Boards: 'Backdoor Partnering'. *Proceedings of the Construction Leadership Conference,* CEMC Seminars.

Mathews, A. A., Matyas, R. M., Smith, R. J., and Sperry, P. E., 1996. *Construction Dispute Review Board Manual,* McGraw-Hill

Smith, R. J. 1994. "Dispute Review Boards for Tunneling Projects Using the ASCE Model," Tunnelina and Underground Space Technology, Vol. 9, No. 1, pp. 37-45

Vorster, M. C. 1993. "Dispute Prevention and Resolution: Alternative Dispute Resolution in Construction With Emphasis on Dispute Review Boards." Report to the Construction Industry Institute.

Vorster, M. C. 1992. *Dispute Review Boards -- Not Just Another Alternate Dispute Resolution Method.* Construction Industry Institute.

Building an environmentally sound future: the construction industry and sustainable development

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Introduction

The Rio conference in 1992 and Rio II in 1997 clearly established a **new international** agenda and priorities in the area of environmental policy and strategy. Environment4 policies can no longer be regarded as optional, marginal or secondary to some other set of objectives. The 21st century will be marked by the implementation of a new paradigm that puts environmental issues at the heart of strategic, corporate and management planning (Whitelegg, 1997). There are several reasons why this major transformation has taken place:

- The immediacy and, urgency of global transport problems including climate change (global warming), ozone layer depletion, acidification, smog and loss of biodiversity
- The realisation that these problems have catastrophic impacts on natural ecosystems and on the life support systems of the planet
- The realisation that these problems have significant economic consequences through insurance losses, larger insurance premiums, “green taxation”, punitive fines and loss of customers as a result of rising "green" awareness
- The realisation that long term economic growth in the traditional year-on-year growth of GDP actually damages the economy through its negative consequence (air pollution, defensive expenditures)
- The realisation that the sum total of these negatives actually reduces quality of life especially through damage to health. The UK government Department of Health published a report in January 1998 showing that 20000 people die each year in the UK from the effects of traffic-related air pollution. Quality of life in cities has declined considerably in the last 30 years measured in opinion surveys covering safety, security, stress and conditions for children and the elderly.

There is perhaps one reason which transcends and embraces all the other reasons quoted above. We have now reached a point in societal development where it is impossible to hide from these problems. In the 19th century wealthy people could escape disease and pollution by separating work and residential locations, living upwind of our cities and retreating to country estates. The late 20th century has removed all these escape/avoidance strategies. Ozone pollution is higher in rural areas than in urban, diseases such as leukaemia have a preference for richer people, pollution in cars is higher than pollution on the side of the street (regardless of model, technology or price), congestion affects everyone and general health problems such as allergies, asthma, skin diseases and psychological problems do not spare the wealthy. We live in an age of the “boomerang“ effect where our profligate use of energy, wasteful use of resources and unintelligent approach to waste and pollution has an unerring tendency to return and exact its damaging toll on life, nature and health

Joined-up thinking

The UK government has predicted that there is a "need" for 4.4 million new homes by the year 2016. The prediction is based on past trends in the growth of new households and the fact that more and more of us will divorce and/or live alone. This has led to a frantic bout of activity by construction companies and by local planning authorities to identify sites and plan for the delivery of new homes. The discussion has polarised around the battle to protect green belts, green land and to preserve the countryside but has not yet focused on the wider implications of simply adding more and more to the housing total without first considering all the alternatives. Building a proportion (yet to be determined) of the 4.4 million new homes on green land is an environmental disaster and will add to all the negatives listed in the introduction to this paper. The bigger failure, however, is the failure to grasp the opportunities to plan in a flexible, intelligent manner to meet this demand by a variety of strategies that conserve resources, reduce energy and transport use and protect the countryside and green areas as an inevitable consequence of intelligent joined-up thinking.

- There are a number of stages in this process and these can be generalised to other debates in construction (e.g. roads and dams) and beyond construction to other sectors of the economy:

- Is the forecast accurate? How sensitive is it to variation in those factors that bring about this kind of demand? Would more support for families with-children reduce divorce? Would social policies that rescue people from poverty reduce the fragmentation of groups?

- If the numbers are accurate what kind of housing can be designed to cope with the demands of those who will be living alone. House builders want to build traditional 3-4 bedroom, semi-detached houses with garages on greenfield sites. Is this the kind of housing that will meet the forecast demand?

- How much spare capacity is there in the existing housing stock? How many empty units? how long have they been empty? Why? What can be done to bring them back into use?

- How-much commercial/industrial/office space is empty? How much of this space. can be recycled for residential purposes? Specifically how much empty space is available in every UK town centre above shops, banks, building societies, fast food outlets etc.? What can be done to bring these back into use?

- What kind of financial framework (taxes on greenfield sites, tax rebates on using former industrial sites, increased taxes on new raw materials and tax breaks on re-used materials) would produce a more intelligent use of resources?

- How much waste land, derelict land, former industrial land is available in the UK and how many units could be built on that land with what kind of provision for green space, woodland and recreational facilities as part of a housing programme on recycled land?

- How much land is occupied by car parks? How much of this could be released for housing development with more effort in the area of sustainable transport (walking.

cycling, buses, trains and trams). An element of joined-up thinking here has the potential to solve both housing and urban transport problems, particularly congestion and the health of urban dwellers

- How many more residential units can be built in a car-free residential area than in a car-rich residential area (with due attention to generous provision of green space in both).

It should be clear from these (far from exhaustive) steps in a logical process of policy making that there are a large number of alternative futures. The one we are likely to be stuck with is quite simply the one that is least imaginative and most severely constrained by entirely artificial, compartmentalised thinking. Even worse the most likely outcome, the "predict and provide" solution is most costly to society as a whole. New roads, new schools, new infrastructure generally will have to be built to serve these new areas whilst existing infrastructure elsewhere will be underutilised or abandoned at a loss to the taxpayer. The transformation of urban and regional space into a low density car dependent state will add to traffic congestion and pollution and illness thus emphasising once more the negatives that are so characteristic of our late 20th century resource profligacy. The relatively affluent occupants of these new houses in former greenfield situations will be remote from the facilities they wish to access, will spend large amounts of time inside their cars "enjoying" a personal chemical cocktail with lung damaging and carcinogenic properties and will be suck in traffic jams. Such is progress.

A way forward

The construction industry is a very important industry. It manufactures the built environment and it puts in place a physical stock of facilities and infrastructure that determines our degree of freedom and flexibility for anything up to 100 years after construction. This puts it in a very different league to the producer of photocopying paper, washing machines or cars. This importance is matched with responsibilities which are shared by all sections of society but have a special relevance to construction: These responsibilities can be summarised under a number of headings:

- The need to engage in and with the wider implications of commercial activity (joined-up thinking) e.g. Natural Step

- The need to adopt strong ethical and human rights policies (e.g. Reebok)

- The need to adopt high environmental standards throughout the business (e.g. ASG, Sweden)

- The need to adopt strong environmental management systems (EMS) through an appropriate standard (e.g. ISO 14001 or EMAS, the European Eco-Management and Audit Scheme)

- The need to be fully part of the region/city/locality in terms of devising and implementing Local Agenda 21 strategies and solutions

- The need to put into practice ees-design principles (e.g. Eco-Logica's study of environmentally responsible design for Scottish Homes, Eco-Logica, 1995)

- The need to plan for the maximum possible waste, energy and transport minimisation. Is enough being done to re-use demolition materials and reduce the use of sand, gravel, aggregates, cement, concrete and steel? Is enough being done to get freight out of lorries and onto trains, waterways?

Conclusion

No one expects the construction industry to abandon a profits driven, commercial perspective. The intelligent enterprise will be aware of the need to seek out new market opportunities, reduce costs, innovate and improve its competitive position. **This is exactly what an environmental perspective in business will deliver.** Environment.4 standards drive a continuous process of improvement in quality and identify opportunities and alternatives for doing things in different ways and in ways that will increase market share and increase profitability. An environmental concern leads to higher standards with associated higher value (price) products and more opportunities to build in (literally) added value. Added value means more services or products added to the basic product in a way that makes more use of the standard inputs of time, energy and overheads into construction projects. A house built to a high environmental standard can be sold at a higher prices and offers more opportunities for the construction company to add products and services that can be charged for.

These ideas have been developed in the context of freight transport (European Commission, 1998). The Commission has shown that there are many more opportunities in freight transport than are traditionally exploited by manufacturing or distribution companies. Many of these opportunities e.g. multi-modal transport and railways have been promoted by environmental arguments with relatively little success but are now being employed by commercial enterprises because they reduce journey times, they are cheaper or they allow expensive resources (e.g. lorries) to be better utilised. The conjunction of commercial imperatives and environmental imperatives provides a powerful metaphor for a completely new approach in the construction industry.

References

Eco-Logica (1995) A life cycle analysis of standard and environmentally high performing homes. Final project report for Scottish Homes, Edinburgh, Scotland. Available from Eco-Logica Ltd, 53 Derwent Rd, Lancaster, LA13ES, UK

European Commission (1998) A source book for the freight transport industry. DGXI, Commission of the European Communities, Brussels. Contact Henning Arp.

Whitelegg, J (1997) Critical Mass: transport, environment and society in the 21 st century, Pluto Press, London

Collaborative performance-based purchasing for sustainable innovation

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Abstract
After an overview of current problems, an orientation is given about different mechanisms for innovation - R&D supply-oriented and demand market-pull efforts. Co-operative and technology procurement may contribute to substantial improvements with higher efficiency/productivity and cost/price reductions.

Experiences from finalised and ongoing collaborative purchasing projects in the construction and energy fields are analysed. In many energy projects the energy use has been reduced by 30-50% through the collaborative efforts by a group of future-oriented housing owners/buyers in Sweden. Similar increases in performance are also shown in the USA and France, using the combined purchasing power of buyers.

This stresses the importance of increasing the role of the owners as buyers in the construction sector. For more promotion of sustainable and environmentally-adapted solutions performance orientation will be very important. As established at the CERF 1996 Symposium, more international collaboration is crucial for formulation of requirements, testing procedures and contract rules, especially concerning long-term responsibility and warranties. The public procurement rules should promote both competition and innovation. The operating costs for facilities should play a larger role through LCC-evaluation of tenders.

As a prestudy, this paper could form a background for further international activities within CIB-CERF programmes and in Swedish programmes for a more efficient construction process.
Keywords: Collaborative purchasing, innovation, performance contracting, technology procurement.

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1 Introduction

1.1 Possibilities

New challenges will meet all actors in the construction sector in the new millenium. Less pollution and resource consuming solutions will be asked for. Developers and suppliers will have to meet the increased awareness with more efficient solutions, which are also less energy-consuming and detrimental to the environment.

The possibilities of accelerating the introduction of more efficient solutions have been experienced in some fields. Reduction of energy use by half, reduction of total costs almost by half and/or speeding-up both the development process and the realisation of individual projects are results achieved by using *co-operative or technology procurement*. With this market-demand process major buyers and users articulate their needs in functional terms, aggregate their purchasing power, and accelerate the innovation and diffusion process. Through parallel work and early involvement of leading buyers and users, the risks are reduced for manufacturers

1.2 General problems in the construction sector

Many low-efficient, existing technical solutions, consuming large resources of energy, cost and time, are the results of a rather fragmented process, split up in phases and branches. It is also dispersed in geographical space. Manufacturers or contractors seldom know the total cost or energy use, and they very seldom meet the end users - being facility managers, maintenance personnel or consumers. Real needs are not articulated in performance terms.

The problematic general situation in the construction sector and future changes in the construction process required for accelerated, yet reliable innovation, have been treated in the Atkins reports on Europe [l].

1.3 Project Earth and operating costs

The impact of energy production and CO, emission on the possibilities of a sustainable situation in the world and the risks of a climate change has come into focus more during recent years. The part of the total operating costs which relate to energy, heating, ventilation and cooling has increased.

The right choice of more energy-efficient components with consideration of life-time costs will be crucial for the total project economy and also for the environment.

The International Energy Agency, IEA, with twenty-five important industrial countries as members has set up a special programme in order to facilitate the development and diffusion of more energy-efficient solutions [2]. The energy sector will be an important area for different policy actions. The recent trends of individualism and privatization in the energy sector will *reduce Government interventions with traditional measures.* Reduction of the use of pure grants and subsidies for energy-efficiency enhancing actions places serious constraints on the application to meet the goals of the Climate Convention and other energy and environment objectives [3]. Procurement methods that stress the long-term impact with the operating costs and open up for efficient new solutions would give all involved organisations competitive advantages.

2 Theories and definitions

2.1 Innovation instruments

Over the years, researchers have consistently debated which *instruments* are most effective in producing *innovations.* (In this context, it is important to note the difference between *inventions* and *innovations,* meaning new products, systems and processes which have left the laboratory and been introduced onto the market.) Some researchers have emphasised the supply side (technology push), others the demand side (market pull). The conclusion drawn in recent times is that initiatives are important on *both* sides, but that most innovations - some researchers say 75 per cent or more - have probably materialised as the result of steps taken on the demand side. Several researchers are agreed that apart from demand-side initiatives, efficient organisation and communication are also important [4 and 5]. Technology procurement is a method of working on the demand side [6].

The importance of involving the *customers* or users at an early stage, had previously emerged in studies from SAPPHO [7] and Rothwell [8], as well as by von Hippel at **MIT,** who has also emphasised the importance of lead users [9].

In many areas, the market is out of balance. There are many buyers, but they are not united, They may have valuable ideas but have difficulties imagining new products. Sellers and manufacturers are not well-informed about what their customers really want.

Interaction between users and producers and organisation of the market have been stressed by Lundvall [5 and 10] and the importance of a "central coordinating agency" by Teubal [11].

2.2 Definitions

Technology procurement may be characterised as an entire acquisition process aimed at directly stimulating innovation. It is not exclusively associated with any particular form of contract though it is closest to design/build contracting with performance requirements [12].

Collaborative purchasing (or co-operative procurement) may include both

- technology procurement (of something not yet existing on the market), and
- acquisition of existing products/systems (for instance among the 25 per cent most energy-efficient ones)

The most influential buyer or a number of *buyers* in combined efforts formulate the requirements and evaluate the products. The market transformation is further influenced by support activities (rebates, information, labelling, awards, etc.).

In some cases, the buyers represent only public organisations. In others, they may include private companies, individuals, or combinations of public and private organisations [13].

Lundvall [14] has also pointed out the importance of the *government in two different roles:* one as the traditional, large, *long-term buyer,* (for the defence establishment, infrastructure, etc.), and the other as an *intermediator, facilitating the building-up of networks and the creation of nodes, or joint organisations, for procurement* (similar to the Consortium for Energy Efficiency and the State Collaboratives in the United States, or the organisations HLM in France and HBV in Sweden, see further below).

3 Experiences - early and lately

3.1 Historical examples

Competitions have often inspired significant innovations. There are some well-known historical competitions and challenges, in which performance criteria were established, such as the solution of the Longitude Problem and the chronometer in the 18th century, and the technology procurement of railway locomotives in England in 1829.

Thus it was shown early on that a competitive element and performance criteria inspired progress by opening the way for innovative ideas.

3.2 Early projects in Sweden

Technology procurement has been used by the Swedish State Railways, SJ, from developing one of the most extensive railway electrification scheme of its time in the early 1900s, to the development of Asea Brown Boveri's X 2000 high-speed train in the 1980s. Performance requirements and strong buyers have also inspired development in energy-supply and telephone projects.

3.3 Construction and energy end-use projects

In some construction and energy areas, it has lately been possible to reduce the use of resources or increase the efficiency by 30-50 per cent in a relatively short time by using performance criteria, formulated by an influential group of buyers. In all the cases, the formation of buyer groups, consisting of leading housing companies with different owners, has been one important element. Special efforts are needed in the fragmented construction sector to get buyers to collaborate.

In some cases (e.g. lifts and bathrooms for existing buildings and energy projects) it has proved important to build up new networks across trade boundaries and establish cooperation between several large buyers. Table 1 illustrates the results from some technology procurement projects

Project area	Result	Energy reduction
Refrigerator/Freezer	From 1.2 kWh/litre comparable volume per year to 0.8	by 33%
Clothes washers & dryers for laundry rooms	From 2.6 kWh/kg of laundry to 1.2	by 50%
Ventilation. Replacement of fans in residential area	From 750 kWh/apartment and year to 380	by 50%
Heat pumps	Two different suppliers chosen for further development & deliveries	by 30 %

Table 1. Results obtained from some technology procurement projects in the energy field in Sweden. [2]

3.4 International examples

Similar methods have been used internationally, e.g. by the French organisation HLM, the Association of Municipal Housing Companies, in developing control systems for apartment houses, "Domotique", a form of intelligent buildings [15], and in the United States, a "Golden Carrot" programme was first used for energy efficient refrigerators (SERP) with 30-35 per cent energy reduction. It is now being followed by the Consortium for Energy Efficiency, CEE (with more than 25 utilities and other organisations all over the USA as members), in a number of fields, such as ventilating and cooling systems.

4 Specific environmental performance criteria

In many of the projects mentioned above - where a more efficient use of energy has been the main goal - there has been a combination with environmental requirements, see Table 2.

Project area	**Performance criteria examples**	**Relative weight in evaluation of tenders**
Refrigerators/freezers, NUTEK, Sweden, 1990	- Energy kWh/litre volume and year. Mandatory/ Desired: 1.0 and 0.8, resp - Removal of CFC - Environment description - Labelling	Quantitative in each part, energy most important. Qualitative between parts (+, 0, -)
Super Efficient Refrigera-tors, "The Golden Carrot", USA 1992	- Energy - CFC replaced by HCFC - Dissemin. of new model	Most important 3 points of 120
Clothes washers, NUTEK, Sweden, 1992-1995	- Energy kWh/kg clothes in standardised washes, different loads and temps. - Use of water - Noise Mandatory/Desired levels	Quantitative in each part, energy most important Qualitative between parts (+, 0, -) Pilot environment assessment
Ventilation, refurbishing in existing multi-family houses, NUTEK, Sweden 1997-1998	Mandatory/Desired levels - Minimum air flow - Noise - Maximum energy use etc	Qualitative and full-size prototype installation in steps, testing
Low-cost housing for the Governm. Delegation for Construction Costs, Sweden 1997	Energy use & environment in appr 20 different criteria Mandatory/Desired	20% weight factor totally for resources (energy) and environmental impact. 4 pilots for testing.

Table 2 Energy and Environment Requirements

Apart from the formulation of energy criteria (maximum kWh per year and comparable volume), the *refrigerators/freezers* project in Sweden also had the outspoken goal to reduce the use of CFCs. Other requirements specified included an environmental impact description and the readiness to show a label to facilitate the dissemination. Similar combinations of requirements for energy and environment have been used in some other projects as shown in Table 2 above.

5 Formation of buyer groups in areas with large fragmentation

As already mentioned, it is very important, especially in the construction field, to try to create a group of property owners who can act as buyers. They should be *future-oriented and be regarded as leading in their field,* (some of them may be so-called *anchor buyers).* It is essential to clearly show that they will be good channels to further markets - besides the first prototype projects. Through the buyer groups and the attention received for a project with large society support sufficient interest will be created among suppliers and contractors.

Many times, the creation of buyer groups can take a very long time. If there is not already a well-established network of people, working together in a trustful collaboration, such a network has to be built up. The buyers have to take part in a common engagement, consisting of clarification of problems, formulation of goals and specification of challenging performance criteria.

Buyers can be identified at several levels and in many areas of the construction process - from property owners, through design/build, general or main contractors, to subcontractors and suppliers of systems, components and building material.

The Swedish organisation HBV with publicly-owned housing companies as members, HSB, which is one of Sweden's major national organisations for housing cooperatives, and purchasing organisations for private property owners, e.g. in Stockholm, are examples of organisations involved in Swedish buyer groups. They are already important for the stimulation of innovative energy solutions.

In the programme set up by the *International Energy Agency, IEA,* mentioned above, a special Market Acceptance Process has been developed, see Figure 1, and buyer groups are being established for different projects.

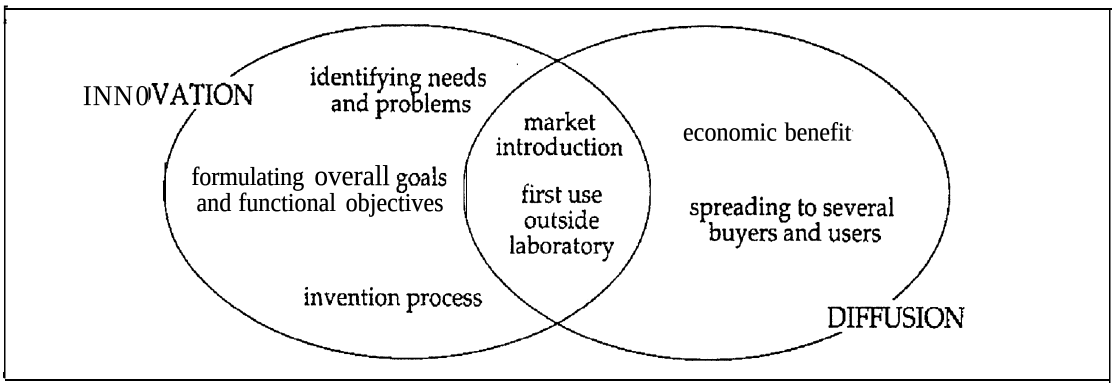

Figure 1 The Market Acceptance Process involves both innovation and diffusion of new technologies and applications.

One of the IEA projects is in the *"wet appliances"* area with a considerably more efficient, Class A type, *heat-pump dryer*. The Netherlands has the project management role. The first appliances will be delivered in the Spring of 1998 in Germany and The Netherlands. Preparatory work is also going on for a *more efficient incandescent lamp* with the United Kingdom as project-managing country, *copiers* (United States) and *energy-efficient motors* (Finland). Other planned areas include Active Solar Procurement.

Different State collaboratives, mainly for more energy-efficient solutions, have been established in the North East and North West of the United States. A number of States are working together, showing joint efforts, and thus creating a larger impact on the market.

We can see other examples now coming up, like "Green" Groups or "ECO" groups, which will work jointly, for instance in the United Kingdom, Germany and the Netherlands.

6 Lessons learned and problems for the future

We know that this working method is rather new with a lot of problems.

1. In many areas, there are no generally accepted *principles for formulating the requirements or for testing.* In some areas it has been essential to develop rules or to accelerate work, for example for refrigerators/freezers, clothes washers and ovens.
2. It will be even more difficult when you want to combine and weigh the different requirements for capital costs, yearly costs, use of limited resources and emissions.
3. The importance of internationally *recognisedperfirmance criteria* has been pointed out at the CERF Symposium in February 1996 in Washington D.C. Such criteria are essential in order to accelarate the development and diffusion of more environmentally-adapted solutions. This work will take a long time.
4. It is essential to build up buyer groups. It takes time to build up trust between organisations that have earlier seen themselves as competitors. It may sometimes be better to *build on already existing networks,* or groups of people, and add additional organisations, buyers and specialists to these groups.
5. It is true that the rules for public procurement, e.g. the European Union Public Procurement Directives and the Government Procurement Agreement of the World Trade Organisation, WTO, are positive to the technology procurement concentration on performance criteria. However, the rules have to be further looked into, so that they can stimulate further innovation and more efficient solutions.

   The Directives stress quite clearly that the request for proposals must include all criteria - preferably also in order of priority - which will be used in the evaluation of the tenders received to establish the most advantageous. It is however not required to state the exact weighting or priority.
6. A combination of different mechanisms for supporting innovation is very important, not only the purchasing or procurement, but also using information activities like labelling, minimum or maximum standards, etc.

8 References

1. Atkins, W.S. International Limited: *Strategic Study on the Construction Sector.* A large number of reports. Commission of the European Communities, F2347, 1992.
2. Westling, H: *Co-operative Procurement - Market Acceptance for Innovative Energy-Efficient Technologies.* B 1996:3. NUTEWIEA, Stockholm, Sweden 1996.
3. Skinner, R. *G: Global Energy Trends and Environmental Implications.* Background paper presented at the 10th International Symposium on Petroleum Economics, Quebec, Canada, 10-20 June 1995.
4. Mower-y, DC & Rosenberg, N: The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies. *Research Policy, No. 8,* 1978.
5. Lundvall, B.Å: *Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation.* In Dose, G et al: Technical Change and Economic Theory. 1988.
6. Edquist, *C: Technology Policy.* Tema teknik och social forandring. / Theme technology and social change, Memorandum./ Linkoping, Sweden, 1990.
7. Rothwell, R & Freeman, C & Horsley, A & Jervis V T P & Roberts, A B & Townsend, J: SAPPHO Updated. Project SAPPHO, Phase II. *Research Policy, Nov.* 1974.
8. Rothwell, R: Characteristics of Successful Innovators and Technically Progressive Firms. *R&D Management,* Vol. 7, No. 3, 1977.
9. Hippel, E von: Lead users: A Source of Novel Product Concepts. *Management Science,* Vol. 32, No. 7, July 1986. Cambridge, Mass. USA. (The Inst of Management Sciences)
10. Lundvall, B A: Innovation, the Organised Market and the Productivity Slowdown. For The Technology Economy Programme. *Technology and Productivity. The Challenge for Economic Policy.* OECD, Paris, France, 1991.
11. Teubal, M & Yinnon, T & Zuscovitch, E: Networks and Market Creation. *Research Policy No. 20,* 1991 .
12. Westling, H: *Technology Procurement for Innovation in Swedish Construction.* BFR D 17:1991, Stockholm, Sweden, 199 1 .
13. SOU 1997: 88: *Upphandling för utveckling.* Betankande från teknikupphandlings-utredningen. /Procurement for development. Report from the commission on technology procurement/. Stockholm, Sweden, 1997.
14. Lundvall, B.A. & Barras, S: *Innovation Policy in the Globalising Learning Economy - Summary.* EC DG XII, 1997. To be published.
15. HLM, EDF, France Telecom, Gaz de France, Plan Construction et Architecture: *Appel à candidature. Interface domotique collective. Cahier des charges fonctionnell d'une base domotique pour l'habitat collectif* Paris, France, July 1990.

Understandings of Environmentally Conscious Procurement Arrangements in Culturally Diverse Circumstances

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Abstract
The construction industry, in common with most others, is becoming increasingly globalised. This has led to the emergence of Architectural, Engineering and Construction (AEC) Enterprises for whom international activities are no longer peripheral, but central to their operations.

In many developed regions of the world, environmental considerations are being seen as increasingly important. This is leading to the application of advanced materials and construction techniques for the construction of the built environment in those regions. Consequently, AEC enterprises have been required to incorporate environmental features into their procurement arrangements to account for increased legislation and to satisfy clients for whom the environment has taken a greater priority.

Where these companies are active globally, they have an ethical, and often a legal, imperative to transfer management and technical expertise to the host country, where that is appropriate. Increasingly, this will include their knowledge and understanding of environmentally sound procurement practices.

However, an obstacle to achieving this is the differences in culture they will encounter when working internationally. Cultural differences can lead to especially pronounced differences in the appreciation of man and his relationship to his environment. This, coupled with different understandings of the nature of procurement, together with differing aspirations and priorities, will present international AEC enterprises from the developed world with major challenges in transferring an environmentally sound approaches to the design and construction of the built environment to host nations.

This challenge can be eased if those enterprises improve their understanding of cultural differences and employ cultural management techniques where they encounter multicultural conditions.
Keywords: Cultural Diversity, Environmental Considerations, International Procurement Arrangements

1 Introduction

As we approach the end of the millennium, two key trends within the construction industry are taking on more importance than ever before. Firstly, the industry is becoming increasingly globalised. While there has been an international construction industry for more than a century [1], an ongoing, political and information led, globalisation process, coupled with changes in patterns of demand for construction activity around the world [2] & [3], is creating an international construction system unlike anything seen before [4].

The second trend is an increasing awareness of the environmental impact of construction activities. It has been estimated that, in the UK, construction, from inception through to end use ("cradle-to-grave") accounts for approximately 50% of national energy use [5]. The Rio Summit in 1992, together with the recent Kyoto Summit, have focused on the need to reduce the impact of man's activities on the environment. As the built environment accounts for such a large proportion of energy consumption, a host of measures are being developed, particularly in developed regions of the world, in order to reduce the environmental impact of construction.

Architectural, engineering and construction (AEC) enterprises operating internationally have an ethical duty to transfer their knowledge and technologies to host countries. As they incorporate more environmental considerations within their procurement procedures, these too must be transferred to countries with procurement practices that are less advanced from an environmental perspective.

One of the main barriers to the successful transfer of technology, is cultural distance. This paper seeks to explore the impact cultural differences may have on relative interpretation of environmentally sound procurement arrangements and the consequences this could have for those companies seeking to transfer knowledge, practices and technologies of this nature.

The paper is not intended to present empirical data. Rather, the aim is to investigate the issues of concern from a theoretical perspective. Thus, the paper draws on existing theory and data in order to advance propositions which can be developed through future research.

2 An increasingly global construction industry

Many anecdotal sources point to the increasingly global nature of the construction industry. However, perhaps the most compelling evidence for this is the increasingly complex weave of cross border holdings within the European construction industry [6]; a phenomenon that is increasingly extending beyond Europe's borders [7]. Bon's [S] ongoing research reinforces this view.

A further demonstration of the process of globalisation within the construction industry is provided by research conducted by the Construction Industry Institute (CII) and American Society of Civil Engineers (ASCE) in the US [9], which notes that chief executives of North American architectural, engineering and construction (AEC) firms identify further exploitation of the global market as a major area of future growth and expansion in what is seen as an increasingly stagnant and saturated domestic market.

3 The environment and the construction industry

The Rio Summit in 1992 and, recently, the Kyoto Summit, have highlighted worldwide concern for environmental issues. The very nature of construction activities mean they have an implicit and significant impact on the regional and global environment [10].

Concern among both clients and governments has resulted in increased demand for procurement measures which act to reduce the impact construction activity has on the environment. Consequently, construction professionals need to be a position to make procurement decisions based on environmental, as well as technical and financial criteria [11]. Ofori [12] suggests that there is a strong case for considering the environment to be an additional project constraint.

The effects of construction on the environment can be considered in three broad areas: global issues; local issues; and internal issues [13]. As they are discussed below, it should be borne in mind that the issues are considered from a specific cultural paradigm. In other cultures and societies, differnet environmental issues may be considered more important or relevant. Furthermore, this is not intended to be either a prescriptive or definitive catalogue of environmental issues relating to construction.

The construction industry is a major contributor to global environmental damage for, a number of reasons. The industry is a high user of fossil fuels. It has been estimated that, in the UK, the construction industry accounts for up to 50% of the nations energy use both in the production, transportation and fabrication of construction materials as well as in the construction and life time use of the building itself [14]. Furthermore, large quantities of CFCs, and other harmful materials, are used in refrigerants, insulation and air conditioning plant and equipment. Additionally, the construction industry uses great quantities of raw materials, obtained by extraction, mining and deforestation. Materials obtained by these means exert pressure on regional environments due to the possibility of flooding, droughts and soil erosion.

Construction professionals need to consider the use of alternative fuels, such as natural gas, and specification of CFC free insulating materials. They should also develop alternative design solutions that do not automatically call for full air conditioning installation. They should consider implementing energy efficiency measures, including optimising daylighting, making use of natural ventilation and passive heating and cooling. Finally, greater use should be made of recycled and renewable materials, while construction waste should be more carefully managed.

Naturally, construction activities also effect the local environment. Air and water pollution are caused by dependence on factors such as road transport, inefficiently designed buildings, high fuel consumption, pollutants from materials manufacture, wood preservatives and dewatering of sites.

Consequently, construction professionals must be more aware of the possible impact of their activities on the local or external environment. In particular, contaminated land should be carefully investigated, with a sound proposal for the disposal, encapsulation or treatment of any contaminants found.

Internal building environments have a significant impact on the quality of our lives [15]. Hazardous and toxic materials in the structure and fabric of the building can effect the well-being of both construction workers and building occupants and can lead to conditions such as sick building syndrome.

Sensitive procurement procedures, such as the use of atria, provision of indoor plants, use of daylight and task lighting and specification of materials that emit lower levels of chemicals, can all help to create acceptable and healthy indoor environments.

4 Technology transfer and environmental procurement considerations

Where AEC organisations choose to operate internationally, they have an ethical, and often legal, imperative to transfer technical know-how to the host country. They also use technology transfer for competitive advantage [16]

The transfer of technology, in all its manifestations, has been well researched in many industries. Technology can be transferred both between industries (the car industry to the construction industry being a common example) and within an industry but between countries (international technology transfer). It is with the latter process that this paper concerns itself. There are also instances of technology being transferred both between industries and internationally, such as the British construction industry adopting production techniques developed in the Japanese car industry.

Barrett [17] describes technology within the construction industry as a continuum, ranging from conceptual 'technologies' such as "open systems" concepts of construction, through managerial 'technologies' such as the "design-build" procurement route, to physical technologies such as a specific concrete mix. This model has been used in. figure 1, with some factors associated with environmental procurement procedures ranged beneath.

CONCEPTUAL	MANAGERIAL	PHYSICAL
Producing a constructed environment that has a lower environmental impact	'Improved design approaches and techniques	
Environmental legislation which effects regulates the activities of the construction industry		Alternatives to/reduced provision of air conditioning
	Waste management procedures	Super insulating materials
'Cradle-to-Grave' analysis of building energy requirements		Improved specification .
		Use of recycled materials
	Use of 'lower energy-embodied' construction methods and materials	High efficiency heating, lighting and ventilation equipment

Figure 1: adapted [18]

Barrett concedes that the model is an over-simplification and the terms ranged below the model, together with their positioning, are open to debate. However, figure 1 is useful in that it serves as a framework for discussing the transfer of environmental procurement issues in relation to cultural differences.

5 The potential impact of cultural differences on technology transfer

Andrews [19] suggests that effective transfer occurs when technology is requested, transmitted, received, understood, applied, diffused widely and improved. A potential barrier to this is the effect of cultural differences. This view is supported by Hemais [20], who developed a model identifying the main dimensions for consideration of international technology transfer. One of the key aspects incorporated within that model is 'cultural distance'. The impact of culture on the transfer of technology within the construction industry, was explored in broad terms at a recent CIB Workshop [21].

In that workshop, Barrett [22] proposes a curvilinear relationship between the effect of cultural differences and the continuum of technologies model, used in figure 1. This proposal is illustrated in figure 2A below.

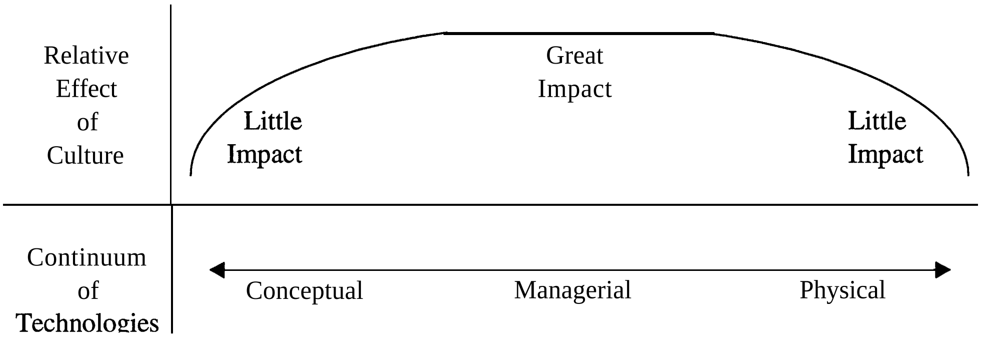

Figure 2A: Varying Impact of Cultural Differences [24]

This is considered to be a critical point, as it implies that culture has little influence on the ability of different societies to assimilate new concepts; that they are easily adopted by the recipients. If it is assumed that, for the managerial and physical stages of technology transfer to be successful, first the conceptual stage must be understood and be 'bought into' by the receiving party, then the conceptual stage is the most crucial. Seymour [23] makes this point when he says:

> " Developing and implementing new technolog[ies] require[s] that the familiar and everyday be looked at afresh and alternatives be imagined and turned into practice." (p. 3)

From a cultural viewpoint, if the managerial and physical features of a given technological concept are seen as 'practices' and 'explicit products or artefacts', then the conceptual aspect of that technology lies within the domain of the 'norms and values' that underlie those practices, products and artefacts [25] & [26].

Practices (the managerial and physical features of technology) are, in this sense, "observable reality" [27], while the underlying values:

> ". ..remain unconscious to those who hold them. Therefore, they cannot be discussed, nor directly observed by outsiders. They can only be inferred by the way people act under various circumstances." [28]

Thus, the value-system of a given society, wherein the concept of the technology will be understood and endorsed, and which is essential if the technology is to be implemented through managerial practices and physical products, is the point where cultures vary in their most fundamental ways. Therefore, at the conceptual stage of the model, the impact of cultural differences is really at its most pronounced and as the technology moves through managerial to physical manifestations of that technology, the impact of culture diminishes. Consequently, the following modification to the model is proposed.

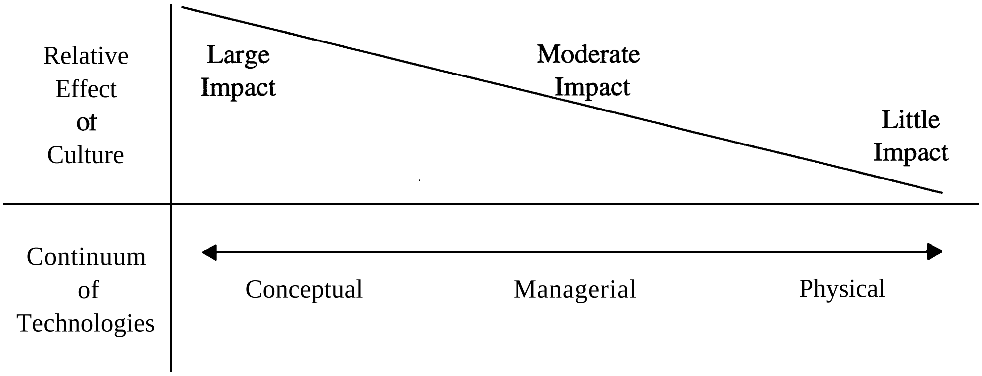

Figure 2B: An alternative view of the varying impact of cultural differences

6 The effect of cultural values have on environmental concern

If the principal cultural barrier to transferring environmental procurement technology lies at the conceptual level, and within the value-systems of differing cultures, then the chief difficulties in transferring that technology will be value based.

As part of his attempt to understand culture, Hofstede and Bond [29] established a series of five cultural dimensions. Two of these dimensions; 'collectivism/individualism' and 'long-termismkhort-termism' are of interest in this respect. This is because environmental issues, especially at the global level, are non-immediate phenomena effecting large populations. As the time difference between cause and effect leading to environmental impact is relatively long (e.g. not immediate), those cultures with a short temporal focus will be less inclined to implement measures reducing that impact than those cultures with a longer temporal focus. Similarly, as environmental impact effects many people, those with a more collectivist orientation will be more concerned in mitigating environmental impacts than those with a more individualist orientation.

Thus, the construction industry of a given society with high scores on both the collectivist and long-termism dimensions would have a higher propensity to incorporate environmental measures within their procurement arrangements than those with lower scores.

The picture is rounded out by another cultural dimension identified by Trompenaars [30] - the role cultures' assign to their natural environment. Trompenaars postulates two extremes (p. 125). On the one hand, there are those who "believe they can and should control nature by imposing their will upon it". Such people are "inner-directed". On the other hand, there are those who "believe that man is part of nature and must go along with its laws, directions and forces". These people are "outer-directed". In broad terms, the latter attempt to live in harmony with their environment while the former live in spite of their environment. Thus, it could be said that construction professionals that come from a culture that is more inner-directed would be less concerned about incorporating environmental measures within their procurement arrangements than those that come from a more outer-directed culture.

7 Conclusions

Undoubtedly, environmental issues will be firmly on the world agenda for the foreseeable future. But it is only now that nations have attained the political maturity to commit themselves to targets for improvement in their environmental impact. The construction industry will have a major role to play in achieving these targets and, with increasing globalisation of the industry, there is an excellent opportunity to share knowledge, expertise and skills for developing the built environment in a way that is less harmful to the natural environment. This knowledge, expertise and skill has, for the purposes of this paper, been considered as a specific group of technologies.

It is argued that, for technology to be successfully shared (or transferred), the recipient must, crucially, endorse the conceptual element of that technology. Culture is one (of many) potential barriers or hindrances to successful technology transfer and, it is contended, has greatest impact at the conceptual stage. Furthermore, the conceptual element of a technology is rooted in the value-system of a given culture.

Drawing on existing theory, it is proposed that, in broad terms, it is possible to determine the propensity for a given culture to incorporate environmental considerations within their procurement arrangements. This knowledge could help AEC companies (or other organisations) in deciding the best way to encourage the construction professionals of various cultures to adopt environmental criteria in construction procurement.

Barrett [31] notes that cross-cultural technology transfer may be more influenced by the difference in professional sub-cultures between, for example, architects and engineers, than by cultural differences at the 'national' level. A pilot study [32] lends some support for this view. However, where there is a wide cultural difference at the 'national' level, (between high-context and low-context cultures [33], for example), cultural differences at a 'national' level must be a (possibly additional) factor.

Finally, Lansley [34] warns that culture generally may be attributed too much importance in effecting technology transfer. While it is agreed that culture is only one of many factors effecting the success of technology transfer, Gyekye [35] notes that:

> "Like science, technology - which is the application of knowledge or discovery to practical use - is also a feature or product of culture. It develops in the cultural milieu of a people and its career or future is also determined by the characteristics of the culture."

8 References

1. Linder, M. (1994) *Projecting Capitalism: A History of the Internationalisation of the Construction Industry*, Greenwood Books, New York.
2. Bon, R. (1992) The Future of International Construction, *Habitat International,* 16:3
3. Bon, R. (March, 1990) The World Building Market, 1970-1985, *Proceedings of the CIB International Symposium on Building Economics and Construction Management,* Sydney.
4. Drewer, S. (1990) The International Construction System, *Habitat International,* 14:2-3.
5. CIRIA (1993) *Environmental Issues in Construction*, Volume 2, Special Publication 94, Construction Industry Research and Information Association, London.
6. Sommerville, J. (1995) "Strategic Advantage Through Cross-Holdings in UK and EU Construction Organisations", *Proceedings of the Royal Institution of Chartered Surveyors COBRA 95 Conference,* Heriot-Watt University, Edinburgh.

7. Barrie, G. (February, 1996) “Lovell’s Strong Potion for Costain”, *Building Magazine.*
8. Bon, R. (1997) *Whither Global Construction ? ECERU Opinion Surveys,* 1992-97, University of Reading.
9. Yates, J. K. (1994) “Construction Competition and Competitive Strategies”, *Journal of Management in Engineering,* 10: 1.
10. BRE (199 1) *The Environmental Impact of Buildings,* Information Paper 18/9 1, Building Research Establishment, London.
11. BSRIA (1992) *Building Services and Environmental Issues: The Background - Interim Report,* Building Services Research and Information Association, Berkshire.
12. Ofori, G. (1992) The Environment: the Fourth Project Objective?, *Construction Management and Economics,* Vol. 10, pp. 369-395.
13. Fortune, C. & Welham, L. (1995) Environmental Awareness and the Design Team, *proceedings of the 11 th Annual ARCOM conference,* pp. 5 1 l-520, University of York.
14. ibid. 5.
15. ibid. 11.
16. Abdul-Aziz, Abdul-Rashid (1991) *Global Strategies of Construction Firms,* Unpublished PhD Thesis, Reading University.
17. Barrett, P. (1997) What, Why, How and Who?, postconference paper submitted for *Cultural factors affecting international transfer of construction management best practice; Workshop, Oslo,* Norway. [http://www.byggforsk.no/bmp/Postconference/pcbarrett.htm]
18. op cit.
19. Andrews, J. (1992) Globalisation and Technology Transfer: Joint Construction Ventures, The Building Seminar, Singapore
20. Hemais, *C.* A. (1996) *The development of a theoretical model of international transfer of technology,* Research Paper No. 249, Warwick Business School Research Bureau.
21. CIB W65 & Norwegian Building Research Institute (June, 1997) Surnmaries of supplementary papers & national state-of-the-art reports , *Cultural factors affecting international transfer of construction management best practice; Workshop,* Oslo, Norway. [http://www.byggforsk.no/bmp/]
22. ibid. 17.
23. Seymour, D. (1997) Scope of Technology Transfer at the Highest Level, postconference paper submitted for *Cultural factors affecting international transfer of construction management best practice; Workshop,* Oslo, Norway. [http://www.byggforsk.no/bmp/Postconference/pcseymou.htm]
24. ibid. 17.
25. Hofstede, G. (1991) *Cultures and Organisations: Software of the Mind,* McGraw Hill.
26. Trompenaars, F. (1993) *Riding the Waves of Culture,* The Economists Books, London.
27. op cit.
28. ibid. 25.
29. op cit.
30. ibid. 26.
31. ibid. 17.
32. ibid. 13.
33. Hall, E. T. (1976) *Beyond Culture,* Anchor Press.
34. Lansley, P. (1997) Cultural Factors Affecting International Transfer of Management Best Practice, supplementary paper submitted for *Cultural factors affecting international transfer of construction management best practice; Workshop,* Oslo, Norway. [http://www.byggforsk.no/bmp/papers/pap_Lansl.htm]
35 .Gyekye, K. (1995) “Technology and Culture in a Developing Country”, pp. 121-141, in Fellows, **R.** (Ed.) *Philosophy and Technology,* Royal Institute of Philosophy Supplement: 38, Cambridge University Press, Cambridge.

Contract Provisions for Effective Dispute Resolution

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Abstract: The U.K. construction industry has extensive experience in the resolution of commercial disputes utilising a variety of processes, which range from the formality of litigation to the relative informality of mediation and negotiation. The procedures available have recently been extended by the introduction if legislation compelling construction contracts to make provision for adjudication to be available to the parties.

This development follows other recent initiatives which are designed to remove confrontation from the construction process and to encourage a more co-operative working environment. The U.K. experience, reflecting both advantages and pitfalls is instructive to other countries where construction disputes are commonplace.

Introduction

The very nature of the construction industry renders it susceptible, more than most industrial activities, to a high incidence of disputes being likely to arise. This scenario is seen throughout the developed World and has given rise to numerous, varied, approaches to dispute resolution.

Underpinning all attempts to systematise the resolution of disputes, in whatever constructional or legal culture the subject has been addressed, has been the recognition that two specific, and often themselves conflicting, demands need to be satisfied.

The first is the fact that the parties involved are commercial **-** probably in their nature and certainly in their outlook. This inevitably, to a greater or lesser extent, places a premium upon the parties preserving (or at least suffering containable damage to) their ongoing relationship.

The second demand is for the process to achieve a result which the parties either accept brings an end to their dispute or, alternatively, which is legally binding upon them. The root of this particular demand is the need, both commercially and legally, for some measure of finality to be achieved.

The steadily increasing burden of work put upon the Courts in many legal systems has made it imperative that effective measures be put in place to spread that workload onto lay practitioners. There is also a discernable movement in the United Kingdom towards decreasing the cost to the taxpayer of running the legal system, both in civil and criminal matters, and requiring parties to commercial contracts to pay for the majority of their dispute resolution, as is the case with “lay determinations”, will contribute substantially to that goal.

Further, where the parties themselves are required to bear, between them in some proportion, the costs of the tribunal, they are likely to have a greater interest in the efficiency of proceedings.

In recent years various developments have occurred in the U.K. with the objectives of expediting and simplifying the dispute resolution processes available to the construction industry, so that the position has been reached where a number of such processes may be selected by contracting parties.

The choices open to a disputant which may be available to achieve a settlement, are:

- negotiation or abandonment
- litigation
- arbitration
- ADR (Alternative Dispute Resolution)

1998 will see added to this list **adjudication** which has hitherto been utilised only in very restricted circumstances, but which is now to be made mandatory for inclusion in construction contracts.

Dispute Resolution in the U.K.

Assuming the dispute is not capable of resolution by consent and the claimant is not persuaded by commercial constraints to abandon the matter, then it has the right open to all citizens to litigate in the courts. Construction cases are generally heard by Official Referees, who have come to specialise in the area and, as a result of the high esteem in which they are held, many parties (or more particularly their lawyers) prefer to litigate their disputes.

Commercial people, however, have for centuries recognised the advantages of an alternative which is private and more flexible, and this has given rise to the widespread use of arbitration. However, the popularity of arbitration in construction appears to be waning and, although international disputes are still commonly referred to arbitration in London, the number of domestic referrals (judged by the number of nominations of arbitrators by professional Institutions) has dramatically diminished in recent years.

More recently, prompted by initiatives in the USA, Alternative means of Dispute Resolution have become more popular, including conciliation and mediation. No form of ADR leads to a binding resolution of a dispute unless both parties agree to any compromise suggested. Where there is such agreement, then action can be taken for any breach of the terms of the compromise reached.

The difficulties experienced by the industry in this regard formed a significant part of the considerations by Sir Michael Latham which led to his report “Constructing The Team” in 1994.

The report includes amongst its recommendations that *"a system of adjudication should be introduced within all the Standard Forms of Contract"* with the express exception of contracts which already contain *"comparable arrangements for mediation or conciliation".* It was also recommended that the proposal for adjudication should be underpinned by legislation.

Latham made three principal stipulations, viz:-

(i) there should be no restrictions on the issues capable of being referred to adjudication;

(ii) the adjudicator's award should be implemented immediately;

(iii) appeals were to be permitted but generally only after implementation of the decision and only after practical completion. Latham did recognise there might be exceptional issues for the courts to decide which could delay implementation.

Adjudication

The use of adjudication in construction contracts in the U.K. has been severely restricted and did not exist at all in standard form contracts prior to 1976. Indeed, the present position is that adjudication is only available if agreed to by both contracting parties (normally by means of a set of adjudication clauses in the construction contract).Nowadays, resolution procedures by a third party appointed under the contract as an adjudicator with powers in respect of defined disputes exist in a number of standard forms of contract and subcontract.

There is no legal definition of the term adjudication although adjudicators appointed by the Lord Chancellor sit in various capacities, for example as Immigration Adjudicator to hear appeals from inferior tribunals.

The Shorter Oxford English Dictionary defines adjudication as "*To try and determine judicially ".* The term *"Judicially"* connotes acting fairly in arriving at a decision. However, it is important to keep in mind that adjudication is not arbitration, and is therefore not subject to the Arbitration Acts unless any of its provisions are incorporated in the adjudication procedures. Some might therefore use the hybrid expression 'quasi-judicial', suggesting that the adjudicator whilst exercising a judicial function has not been appointed an arbitrator under the Arbitration Acts.

The very nature of adjudication is different from the more formal processes of litigation or arbitration, in that the expectation is that a result will be declared by the adjudicator in a relatively short timescale. This should encourage parties in its use, even for relatively minor disputes, since costs incurred are not likely to be great. Given the probable timescales involved - days or weeks rather than months - the adjudicator is expected to give a Decision without the benefit of the sort of comprehensive evidence and legal submissions which an arbitrator or judge could expect. There is, as a result, understandable concern over the abilities of prospective adjudicators and a number of reputable professional Institutions have established rigourous training courses to meet those concerns.

The House Grants, Construction and Regeneration Act 1996

The Act received the Royal Assent on 15th July 1996. Part II of the Act, that is Sections 104 to 117, deal with construction and can be referred to as **"The Construction Act".** That Part deals only with two matters, both of which address issues raised by the Latham Report. These issues are:

- payment provisions, and
- dispute resolution by adjudication.

The "Construction Act" will not come into force until the Secretary of State for the Environment, Transport and the Regions, issues the necessary Statutory Instrument, which is expected to bring the Act into force around April 1998. Sections 104 to 108 deal with the subject of adjudication and give every party to a construction contract the right to refer any dispute arising under the contract for adjudication complying with the statutory code.

The application of the Act is subjected to several restrictions, a number of which may operate to the disadvantage of the industry generally; although it should be kept in mind that parties to construction contracts may chose to allow for adjudication in their contracts, even though not strictly compelled to.

- The Act is not retrospective. It applies only to contracts entered into after the commencement of the Act (section 104(6)(a)), whenever that is decided by the Secretary of State.

- The Act applies to England, Scotland and Wales but not Northern Ireland (section 104 (6)(b)).

- The limited definitions of *"a construction contract"* and *"construction operations"* (sections 104 and 105) means that the Act applies only in respect of work of a type defined within it. Whilst the definitions include all work which would generally be expected to fall within the ambit of contractors and subcontractors, there are several surprising exclusions. The Act also extends beyond the tasks of constructing to include application to the appointments of designers and advisors.

- The Act does not apply to contracts with residential occupiers (section 106), although subcontracts placed in connection with work which is ultimately for a residential occupier must comply with the Act.

- The Act only applies where the construction contract is in writing (section 107) but the definition given to a "contract in writing" is extremely broad and is likely, in practice, to exclude only the contract in which nothing at all is ever written.

- The adjudication procedure is a right operative at the behest of either party and is otherwise not mandatory.

Adjudication provisions (section 108)

- This section starts off with what is, at first sight, a very simple and straightforward statement:

> *"Subject to the aforementioned restrictions any party to a construction contract has the right to refer a dispute under the contract for adjudication under a procedure complying with this section."*

This simple procedure is likely to have a number of teething problems and the following points should be noted:-

* adjudication is not obligatory but is available only if a party exercises the right to call for it;

- adjudication is limited to disputes *"arising under the contract"*

  what is a *"dispute"*? - an assertion by one party denied or rebutted by the other

  "under the contract" connotes a narrow meaning (compare, for example, *"arising out* of' which carries a wider implication), but the wording is wide enough to cover all disputes emanating directly from the contract though it does not cover misrepresentations inducing the contract and any action in tort;

If the procedures set out in the contract do not comply with section 108 then the government "Scheme for Construction Contracts" will apply. By this means parties whose contract does not provide for adjudication as demanded by the Act will have terms implied into that contract, effectively bringing about compliance.

On the assumption that the construction contract complies with section 108, the procedure when compared with other dispute resolution processes, reveals that:-

- the parties can consent, by way of particular construction contract provisions, that the adjudicator's Decision is final and binding;

- save where the parties do agree as above, the Decision of an adjudicator binds the parties unless and until that Decision is overturned by litigation, arbitration (if the parties have an arbitration agreement) or by subsequent agreement of the parties;

- the adjudicator is not acting as an arbitrator but making an expert determination;

- the adjudicator is to be given immunity from being sued save where having acted in *"bad faith"*;

- the adjudicator is obliged to follow the procedures set out in the contract and/or his/her terms of appointment;

- the adjudicator is not bound to give reasons unless obliged to by the particular procedures in the contract;

- the adjudicator can act inquisitorially, is seemingly not expected to carry out a judicial hearing and will normally never need to hear oral evidence.

Benefits and drawbacks of adjudication under the Act

Some of the perceived benefits are:

- a universal right for any party to a construction contract to have a dispute *“decided”* by an independent third party, promptly;

- once adjudicated it is thought the majority of decisions will be accepted leaving the parties free to proceed with their normal contractual obligations;

- the adjudicator’s Decision has to be implemented before a challenge by litigation/arbitration can be made;

- it should be a very quick and cheap process;

- it should promote a better atmosphere on contracts by minimising major confrontational situations;

- it can enable the adjudication to be accomplished with a relative minimum of expert and lawyer involvement.

The features which distinguish adjudication from other dispute resolution processes are the combination of speed of application with the binding effect of the adjudicator’s Decision. The particular benefits arising from the effective use of the process are that the parties should achieve an independent decision in a relatively short timescale (within 35 days of the Notice of Dispute under the Act), and this should enable the parties to preserve a co-operative working relationship.

The process of adjudication, as now to be statutarily imposed in the U.K., is not without potential drawbacks, however. Those suggested by certain commentators include

adjudication may not result in a fair Decision and could resemble “palm tree justice”;

- as ever, the large and wealthy parties can prepare more sophisticated submissions and/or are better able to challenge an adverse Decision in subsequent arbitration/litigation;

- it will lead to a proliferation of formalised disputes;

- there is a relative absence of persons presently able to properly fulfil the role of adjudicator. One of the objects of the Academy of Construction Adjudicators is to address the present shortage of trained adjudicators. By the end of 1997 almost 200 construction practitioners had successfully completed the Academy's training scheme.

- some disputes are not capable of proper adjudication;

- to implement a Decision which is subsequently overturned by arbitration/litigation could lead to bizarre results, for example where alleged non-conforming work had been taken down and that decision was subsequently overturned.

The appointment of adjudicators is also a cause for concern, particularly since the Act expects the appointee to be in place within 7 days of the Notice of Dispute being served by the referring party. The parties could name an adjudicator in their contract from the start, but a dispute might arise which was outside that individuals sphere of technical expertise. The alternative, which is expected to be most widely used in practise, is for the parties to select their adjudicator (or have one chosen for them by a nominating independent body) after the dispute has arisen. Either method of appointment is permissible under the Act.

None of these matters are considered likely to prove insurmountable, however, and can be overcome by considered drafting of other terms of the contract and by the parties themselves ensuring that the process works.

Summary

Although adjudication is not new to the U.K. construction industry, its use hitherto has been limited to restricted application in a number of specific standard form contracts. Even there the number of references of disputes to the selected adjudicator were few. Many approved adjudicators, even when named in contracts, have achieved much more than 1 reference per year.

The implementation of the "Construction Act", however, can be expected to cause a significant increase in the number of disputes referred to an adjudicator. That is not to say that the number of disputes is likely to rise; rather that adjudication will come to be seen by the parties to construction contracts as an extremely useful and practical mechanism for assisting them to achieve their objectives for the project - for uniting the parties rather than dividing them.

Critics of the Act and of the process of adjudication generally, who are largely drawn from the ranks of the legal profession and thus have a vested interest in defending the more formal methods of dispute resolution, claim that the process, for a variety of legal and practical reasons, will prove unworkable. That is not the view of the construction industry at large, who see adjudication as a means of retaining control of their disputes and the cost of their resolution.

Environmental Assessment of Buildings, Building Operations and Urban Areas

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Abstract

Sustainable Development is one of todays key issues generating a wide range of concerns ad initiatives world-wide. If the maintenance of economic activity, growth and, therefore, quality of life for mankind are to be successfully balanced with a sustainable environment, measurement will be crucial.

Buildings account, directly or indirectly , for a large share of societies environmental impacts. Since 1990 BRE has been developing and operating environmental assessment methods and guidance aimed at minimising the impacts of buildings BREEAM is a consensus based environmental assessment method for buildings, embodied in an accreditation scheme. BRE's environmental management 'Toolkits', launched in 1995, provide a means of reviewing the impacts of an organisation and prioritising actions by measuring both financial and environmental burdens. Both have gained wide spread support and use in the UK and substantial interest internationally. A range of building types is being covered by BREEAM and this is increasing most recently through guidance for the Retail sector and a 'Toolkit' for schools.

Due to limitations of knowledge, consensus or practicable solutions there are significant areas that these tools have not been able to cover. This paper explores three of these issues and the work that BRE has carried out on them. It sets out the potential for developing practicable industry measures and guidance capable of being included in these tools.

Key words: Sustainability; Environment; Buildings; Assessment; Guidance; Management; BREEAM; Embodied CO_2; Visual impact; Weighting .

Environmental Assessment of Buildings, Building Operations and Urban Areas

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1. Introduction

The concept of sustainable development is gaining high profile political and media interest since it is increasingly being seen as one of the key issues for the global society. The protection of the environment, a central plank of sustainability, is generating a wide range of initiatives world-wide. At the Rio conference a process of international collaboration was initiated and despite many reservations the 1997 conference on greenhouse gas emissions at Kyoto moved this process forward.

Buildings are linked to a large number of environmental impacts. In the UK and other Western European countries, buildings account for about 50% of primary energy use (and hence CO_2 output), far outweighing the contribution of either transport or industry. Buildings are, however, vital to the continuing economic health of our societies. This link between environmental concerns and continued economic and social activities - exemplified in buildings issues - central to achieving sustainability. The balance between protection and development is not easy to and will be debated well into the future. But any solutions proposed will have little basis if impacts are not measured and analysed.

Since 1990, BRE has been operating and developing environmental assessment methods and guidance for a range of building types. The Building Research Establishment Environmental Assessment Method (BREEAM) is a consensus-based environmental assessment method, embodied in an accreditation scheme. This method has provided, for the first time, a simple and practicable assessment of the environmental impact of a building across a wide range of issues relating to the global, local and internal environments. It builds on marketplace incentives to achieve real and meaningful reductions in the environmental impacts resulting from buildings and their operation by providing and demonstrating direct benefits. It has gained widespread support and use in the UK and substantial interest internationally. BREEAM was initially developed for new office buildings [1] by BRE in collaboration with ECD Energy and Environmental Consultants and industry. There is now a portfolio of assessment methods covering existing Offices, industrial units, superstores and supermarkets and new homes [2][3][4][5]. Guidance for the retail sector is currently under preparation [6]. Previous papers presented by the authors and others set out the background and development of the scheme. In parallel, BRE has developed the Office and School Toolkits [7][8] which take the concept behind BREEAM into new management areas related to building and office. These provide simple environmental toolkits for building occupiers to allow them to assess both the environmental and cost impacts of their activities and so help managers to prioritise their future action plans to maximise improvements in both fields. Linking the environment with costs in this way gives a very powerful message to business that it is in their own interests to address environmental issues.

BREEAM has become widely accepted in the UK construction and property sectors as a representation of current best practice in environmental design and management. For some time, though, BRE has been aware of substantial gaps in the coverage of issues owing to a lack of knowledge, consensus or practicable solutions for building owners and designers. There is also the need to expand the scope of BREEAM into the wider realms of sustainable construction. It is probably not sensible or practicable to include major economic and social issues within a simple tool and at the same time preserve its user friendliness. However, there is a need both to continue to assess environmental issues and to extend the same basic approach to other sustainability criteria. This paper explores three issues that might be included and the potential for developing practicable, consensus-based measures capable of being included within tools such as BREEAM and the Toolkits.

2. Embodied energy and CO_2

The issue of the embodied energy in a building has become an issue both in research and practice. In reality the CO_2, SO,, NO_x etc. embodied in materials and components are more of a concern as energy content is a cost issue that the market place will tend to regulate through competition.

The *Green Guide to Specification* [9] is one source of guidance available to designers. It is a system of environmental profiling for building specifications in the UK commissioned one of the UK Government's largest property portfolios, Post Office Property Holdings. The publication is designed to be an easy-to-use reference document for busy professionals actively engaged in design and construction and is based upon an extensive collection of existing , mainly public domain, data. It provides A, B or C environmental ratings for 120 building products, components and materials in terms of embodied energy, emissions, consumption of resources, recycling issues and toxicity. Details of the Green Guide and its development were presented in a keynote paper at the CIB-TG8 conference on Buildings and the Environment in Paris in June 1997 [10]. Whilst its authors, Shiers and Howard, recognise the limitations of the data on which it is based, they are also clear about the advantages of a book with a simple rating system.

This publication was devised to provide a useful tool for designers working for the Post Office. There are, however, a number of limitations to its wider use. The specifications covered are limited to those most used by the Post Office and some significant elements are not included. Despite this, the Green Guide has been rapidly accepted by designers, especially for use at the early design stage, even though it was not marketed vigorously.

BRE is now collaborating with the Post Office in further developing the Guide. The new version will have a wider range of specifications and more refmed categories included in the assessment. These will ensure that sufficient options are included for a credible assessment to be made for many types of building. The revised guide may be incorporated into future revisions and versions of BREEAM although the basis on which credits would be assigned has yet to be determined. It is expected that the Guide will be updated every 3-5 years in concert with BREEAM revisions seeking always to use the best available data.

Simple guidance of this form is needed for use by designers at the early stages of a design process when key decisions are being made. It is complementary to the more complex Life Cycle Analysis (LCA) methodologies now being developed and to the use of the UK National Database of Construction Materials, Components and Buildings due to be published by BRE in December 1998.

Although the market has eagerly accepted the simple guidance offered in the Post Office publication, its authors have been keen to test it against other established methods. The only comparable method is that offered by the *Handbook of Sustainable Building* [1 1], which is based upon a methodology devised for the Dutch Government. The two books use similar design specifications and environmental parameters, and share a common purpose. In a comparative study by Thomas in 1997 [12] which compared ratings given for 2 1 building specifications and materials it was demonstrated that despite having been derived from different methodological backgrounds and data sets, the two methods provided similar rankings for similar materials and design specifications. Most significantly, the "Preference levels" in the Handbook show a strong correlation with the Green Guide overall A, B, C ratings in the advice offered, as shown in Table 1 below. This finding gives to designers.

The Green Guide Ratings:	Environmental Preference Ratings:			
Total Number of:	1	2	3	Not Recommended
A's	5	6	0	0
B's	0	2	1	1
C's	0	0	2	4

Table 1 Comparison of the *Green Guide to Specification* A, B, C ratings with the *Handbook of Sustainable Building* Environmental Preferences

3. Visual Impact of Buildings

A major impact of buildings and development on communities is the visual impact that they have. This has both a profound environmental and social impact. Much has been written on this subject but little attempt made to develop assessment methods despite its being one of the more contentious issues related to development. In 1995, BRE commissioned the University of Surrey, Department of Psychology, to carry out a survey of views and to test some of the current theories. The survey although small, included a representative sample of individuals from the major interest groups as follows:

- developers
- architects
- other design consultants
- planners
- the public

Each group was asked to comment on a set of visual criteria developed from published material on the subject and to express their willingness to address these issues.

As expected, there was substantial disagreement on the issues that should be included in any assessment and in the methods suggested for assessment. The most supportive groups were planners and the public followed by architects. Developers were the least keen to see visual impact addressed as an issue. They feared over-prescriptive recommendations from the process and tended to concentrate on issues relating to the context such as landscaping and signage rather than building details. However, all groups were generally positive to the concept of assessment provided that this non-prescriptive approach were followed.

A range of issues were generally agreed as being relevant. These can be categorised as:

- form and massing
- external materials
- context - urban / rural / townscape
- landscaping
- security
- internal / external visual links

Less consistent was the means of assessing these. Few can be easily quantified so much of the assessment that currently takes place is qualitative. This may not be a problem provided that a consistent approach is adopted. The fmdings suggested that BRE should not attempt to pass any judgement on this issue at this stage but that there was great value in developing a consistent process of appraisal by establishing a protocol capable of aiding the presentation of information whether in planning negotiations, public consultations, technical reviews or assessment.

It was felt that implementing an assessment only on those issues where consensus can be reached would lead to a piecemeal methodology that failed to assess the overall impact of a building. This would lead to substantial and justifiable criticism. This emphasis on the process rather than the product, which formed a key recommendation of the consultants, avoids the need for subjective judgements to be made. When the findings where discussed by an expert panel of planners, designers and conservationists there was unanimous support for this recommendation.

This solution seeks to elicit a set of simple statements on a number of issues relating to the design process. Examples might be:

1. **How have you considered the context of your development in the design process?** This could include reference to local and vernacular styles; regional characteristics; surrounding uses/forms of buildings; creation of urban / public space.

2. **What is the zone of visual impact?** This could indicate range of distances and directions form which the development will be seen and the duration of view under normal circumstances; relative heights to neighbours and local topography; the need for visual statements; appropriateness of design details.

3. **How have you considered the relationship of the function of the development to its form?** This could cover relationships of the function to design and surroundings; relationships of internal / external environments; legibility of design and form; safety and access issues.

By asking for simple statements such as these and guiding the content required, much can be determined about the degree of thought that has been given to these issues during the design process. It also makes it easier for others to understand the reasoning behind design solutions by defining a common language.

In addition, the study produced a range of consensual criteria and identified many of the gaps in these. This highlights the need for ongoing research in this area including discussion with the numerous groups of interested parties. It could also lead to better quality planning guidance. BRE is exploring these requirements further.

4. Weighting of environmental issues

BREEAM currently assesses issues within three categories - Global, Local and Indoor. A rating is awarded based on the number of credits achieved in all three categories to encourage a balanced approach. In addition there is a degree of weighting given to issues by the number of credits awarded for each. The scale as it stands, however, can not be seen as a scientifically rigorous one and for this reason BRE has, for some time, carried out research which is ongoing into assessing the environmental weighting of the issues assessed.

Research was carried out for BRE by KPMG Management Consulting in 1992 to explore the potential for carrying out some form of weighting in the updated BREEAM being prepared at that time. Although this did not to lead to the inclusion of a rigorous weighting in the new version, it did flag the potential routes that could be explored. The study found three basic approaches which could be adopted for assessing the relative importance of impacts relating to building performance:

- Qualitative assessments are generally based on subjective judgements to determine performance. In each case guidance or expert judgement is used but a high degree of subjectivity remains. The potential for bias is an appreciable problem in such assessments.

- Quantitative assessment techniques have been developed in response to the demand for a more scientifically rigorous assessment. Such methods exist for many environmental impacts although not all, but give little help in deriving a rating methodology. They are useful in judging single issues but do not help in comparing relative importance of issues.

- Monetary valuation of environmental impacts faces the basic problem that many environmental ‘goods and services’ are free. There is no market operating to determine a price. A number of techniques exist to aid valuation of such impacts.

  - Market Value approaches are based either on the decreased value of output and increased cost to repair environmental damage or replacement costs.
  - Household Production Function methods use expenditure on complementary or substitute goods as a means of valuing a non-marketed environmental good. The primary method for doing this in buildings is preventative expenditure i.e. the cost of taking steps to avoid the damage.
  - Hedonic Pricing methods rely on the increase in property value as the basis for evaluating environmental benefits and so provide a measure of the willingness to pay for minimisation of environmental damage.
  - Contingent Valuation methods consist of asking people in a structured way how much they would be prepared to pay or receive in compensation for a specific change in environmental quality.

The study concluded that experience in the practical application of weighting in environmental assessment was limited, making it impossible to include a rigorous assessment in the update at that time.

In 1993 Davis Langdon and Everest carried out further research for BRE on the weighting of environmental issues. This was aimed at moving towards a robust and validated scale of the impacts covered by BREEAM. The study used the monetary approaches to attempt to provide a figure for each issue that could simply be added to give an overall monetary rating for the building. The study used a cause/effect matrix to enable multiple causes such as fuel consumption, recycling and site ecology to be broken down into single quantifiable effects such as CO2 emissions, resource depletion and an ecological index value. Such single effects can then be given a quantifiable value which can be summed to give an overall score for a building in respect to that effect. An effect fingerprint can be produced from this data to give a visual indication of the buildings impacts. By giving each effect a monetary value an overall environmental cost can be achieved for the building. Global and resource issues were relatively easy to both measure and value in monetary terms as the research data available is extensive. However, there is a marked lack of data on local and indoor effects. This flagged the need for research to be concentrated in these areas if BREEAM is to make use of such a method.

In the absence of such a scientifically robust methodology BRE used the Ecopoints system ,developed and subsequently refined by PRe Consultants, in the Office and School Toolkits. This provides a mixed quantitative and qualitative approach. The results are open to criticism but BRE believes that they provide a sensible indication of the areas which require most attention. They are used in the Toolkit to highlight priorities and are not an attempt to provide a rigorous quantification of the environmental effects. As such, they are not appropriate in their current form to a formal assessment method such as BREEAM. Within the Toolkits economic impacts of issues are also considered in terms of direct costs. All issues assessed are presented in the form of cost and environmental fingerprints which allow priorities to be made quickly and easily, possible actions to be explored and action plan developed and monitored. Figure 1 shows the structure of the School Toolkit which is a software tool. This has received strong interest and support in business circles and demonstrates a way of increasing the relevance and take-up of industry tools such as these.

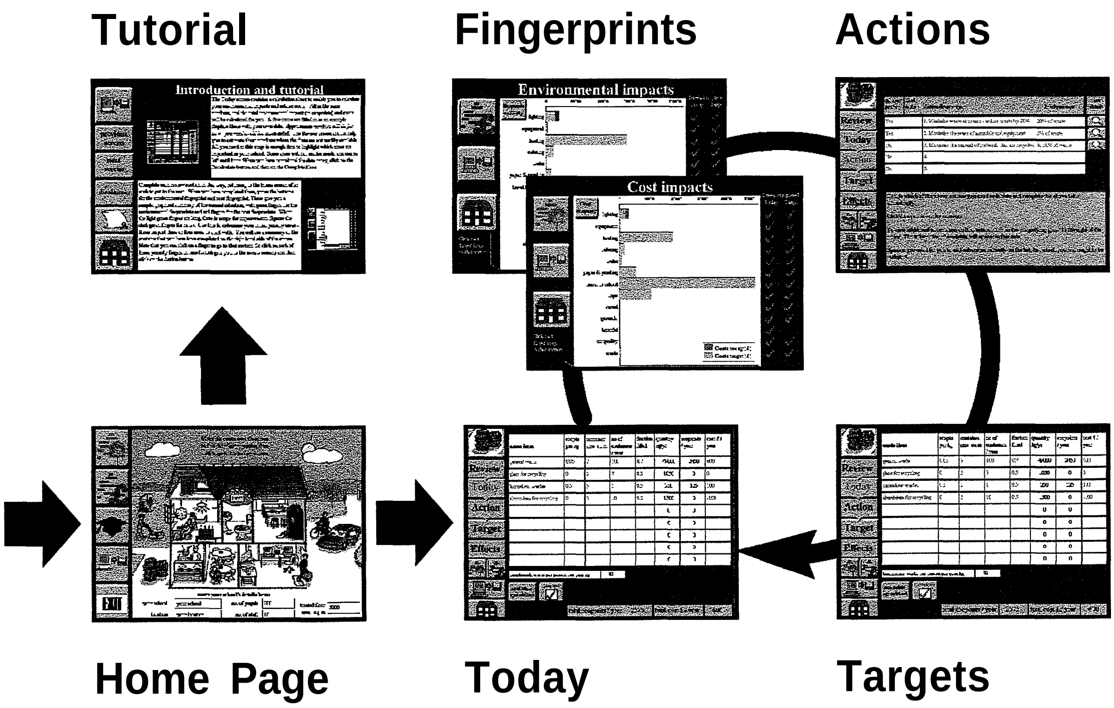

Figure 1 - Structure of the BRE School Toolkit

BEES, recently launched in the USA [13], provides a further example of a method that allows measurements of both cost and environmental impact. The benefit of this approach is that it allows individual designers and their clients to weight the importance to them of these issues by setting their own priorities with quality information.

BRE is currently carrying out a study aimed at establishing the degree of consensus that exists on the broader range of issues relating to Sustainability. Interest groups have been brought together to discuss and weight a range of issues derived from an Internet search. The issues covered are, therefore, representative of those relevant to policy and practice in society, government and business. The project has not reached the stage where any analysis can be presented as the discussion groups are still proceeding. Preliminary findings have shown a surprisingly strong consensus on many issues throughout the range covered. The work is unlikely to lead to a set of firm consensus weightings at this stage although there are promising indicators for a future stage. It should pave the way to more in-depth studies and will help to guide BRE on weightings for new versions of BREEAM.

5. Conclusion

BREEAM has worked well in influencing the design of new buildings and especially offices. Experience gathered from the development and operation of the methodologies over the last six years, together with the research carried out on areas not yet covered, have highlighted the strengths and weaknesses in current BREEAM versions in achieving their aim of stimulating environmental improvements in the UK building stock. BRE's ability to include new issues within such tools in a meaningful and practicable way is being expanded.

The current work being undertaken at BRE to revise the methodology for offices will address many weaknesses through a substantial expansion and restructuring of the method. It will also widen the range of issues beyond the buildings envelope and begin to make links to other areas of concern in terms of sustainable development. The revised method is due to be launched later this year. It will provide the basis for future revisions and additions to the BREEAM portfolio. It will also guide future development of related industry tools by BRE to enable construction to make a full contribution to the achievement of sustainable development.

References

1. J J Prior. ***BREEAM 1/93 - an environmental assessmentfor new office designs.*** Building Research Establishment. Report No. BR234, 1993.

2. S J Leach; M P Attenborough; J V Doggart; R Baldwin; P B Bartlett. ***BREEAM 4/93 - an environmental assessmentfor existing offices.*** Building Research Establishment. Report No. 240, 1993.

3. C R T Lindsay; P B Bartlett; A Baggett; M P Attenborough; J V Doggart; ***BREEAM 5/93 - an environmental assessmentfor new industrial, warehousing and non-food retail units.*** Building Research Establishment. Report No. 252, Garston, 1993.

4. V H C Crisp; J V Doggart; M P Attenborough. ***BREEAM 2/91 - an environmental assessment for new superstores and supermarkets.*** Building Research Establishment. Report No. BR207. Garston, 199 1.

5. J J Prior; P Bartlett ***- The Environmental Standard, Homes for a Greener World -*** Building Research Establishment. Report No. BR278 Garston 1995

6. JJ Prior ***- Environmental Design and Management Guidance for the Retail Sector -*** Publication under preparation - BRE, Garston. Due for Publication 1998

7. A Bishop, H Durrant, P Bartlett; ***BRE Office Toolkit -*** BRE Report No. BR285, Building Research Establishment 1995

8. A Yates, A Bishop, C Reid; ***The School Toolkit (software) -*** BRE/PA Consulting Group 1997

9. Shiers D and Howard N P, ***1996. The Green Guide to Specification. An Environmental Profiling System for Building Materials and Components.*** Post Office Property Holdings.

10. Shiers D and Howard N P, 1997. ***The Design and Development of an Environmental Profiling System for the Specification of Building Materials and Components - CIB-TG8, 2nd International Conference on Buildings and the Environment, Paris, June***

11. Anink D, Boonstra C and Mak J, ***1996. Handbook of Sustainable Building: An Environmental Preference Method for selection of materials for use in construction and refurbishment.*** James and James.

12. Thomas M, ***1997. A Comparison between The Royal Mail Green Guide to Specification and The Handbook of Sustainable Building.*** Davis Langdon and Everest.

13. Lippiatt B, 1997. ***BEES.*** NIST, USA

Sustainable maintenance in transition economies

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Abstract
The problem of maintenance has been considered in European and world scientific circles for a long time. This is because structural changes in investment go in hand to hand with economic development and business advances. The level of investment in the construction of new structural projects is constantly decreasing and the level of assets invested in the maintenance of existing buildings rising. Experience shows that usage, maintenance and reconstruction costs far outweigh the cost of initial construction.

Much research has been done in this field, but maintenance problems differ from country to country. Differences are particularly noticeable in the average age of the building, its original quality, technological approach and materials used in its construction, climatic characteristics, type of ownership, economy of the country in question etc. Seven years ago, Croatia changed its economic and political system from socialism and a state-run economy to a market economy, thus bringing the problem of sustainable maintenance into the focus of scientific and professional research.

The paper reviews the full scope of issues related to the maintenance of buildings in the Republic of Croatia in general, and in its capital, Zagreb, in particular. The districts of Centar, Novi Zagreb, and Tresnjevka have been taken as samples, being historically and architecturally very different. Each district, however, proved to be a very homogeneous sample regarding the main characteristics of buildings, and can therefore represent a model for setting priorities for sustainable maintenance. Analysis of the economic and technical indicators within the life cycle analysis may indicate the unjustifiability of further maintenance or full reconstruction of a building. However, the historical, cultural and architectural values of the architectural heritage of any city must be preserved, and Zagreb all efforts in this respect are being exerted.

A new model for maintenance sustainbility is being developed at the Faculty of Civil Engineering which is especially adjusted to the specifics of transition countries, one of which is Croatia.
Keywords: sustainable maintenance, buildings, transition economies, heritage

1 Introduction

The problem of maintenance has had high priority in European and world scientific circles, as the economic development and progress of a country changes the structure of investments. The proportion of investment in the construction of new buildings continuously decreases as investment in the maintenance of existing structures increases [1].

This is especially the case in old city centres. Analysis of economic and technical indicators within the life cycle cost analysis may indicate to the unjustifiability of further maintenance or full reconstruction of a building [2, 3]. However, the historical, cultural and architectural values of the architectural heritage of any city must be preserved, and in Zagreb all efforts in this respect are being exerted.

The problem is how to preserve the original appearance of the building and, at the same time, ensure the safety and quality of usage. Sustainable maintenance implies that buildings are to be renewed in a way to enable people and communities to provide for their social, economic and cultural well being without compromising the ability of future generations to fulfill their needs and preserve their heritage.

The sustainable maintenance problem is very complex, and becomes a serious challenge to researchers in transition countries. These processes have fully emerged in Croatia which has embarked on the road to market economy and private ownership.

2 The Problem of Maintenance of Buildings in Croatian Cities

To make possible an understanding of the problem confronting municipal authorities and the population in Croatian cities in their efforts to ensure sustainable maintenance we first need to explain the specifics of the condition inherited from the past system.

The major part of the housing space in Croatia was privately owned until 1945. After World War II, the communists come to power in former Yugoslavia and nationalised all private property. People owning several flats or houses were left with a single large (5- or 6-room) flat or two smaller (1- to 2-room) flats, with the remaining space being given to new right-to-use tenants. Other real estate, like land, factories, retail outlets etc. became the property of the Yugoslav state which took over their maintenance and management.

The maintenance of buildings in the past has been nonsystematic and without planning, with a significant difference in treatment of housing buildings and public buildings (theaters, schools, hospitals, courts, administration buildings etc.).
Public buildings were under the direct jurisdiction of respective ministries (culture, education, health, administration etc.). There was always a shortage of funds for their regular maintenance, and repairs were undertaken only when it became critical. Partial or integral reconstruction of a building would then be undertaken. According the data from 1995, 5% of the total funds earmarked the maintenance of public buildings were spent on regular maintenance, and 14% on repairs. Investments in reconstruction represented 8 1% of the maintenance funds which amounted to US$53.5 million [4].

The housing space was shared between the real owners of flats and the right-to-use tenants, with identical rights as the real owners although the flat was either state- or company-owned. The right-to-use institution was specific for the socialist system in

Yugoslavia and has a strong impact on the maintenance of housing buildings. The users on housing blocks were not bound to maintain the common parts of a building (roof, staircases, facades etc.) since it was so-called social ownership.

The state, via its funds, contributed to the maintenance of housing buildings in the form of regular maintenance (16%), reconstruction (39%) and repairs which included emergency interventions (44%). The amount thus spent in 1995 was US$44 mil. [4].
After 1991 and the break of Yugoslavia, new socio-economic relationships were established in Croatia. The law on the purchase of flats has enabled the former right-to-use tenants to acquire ownership of real estate under very favourable conditions. The maintenance of all buildings in the Republic of Croatia with two or more co-owners is regulated by the Law on Ownership Relations which imposes on the new owners the financing of the maintenance of buildings. For instance, the costs of renewal of the facade on a 3-storey high building in Zagreb, built in the 1930-s average approximately US$150 000. The Law was enacted in 1996 and started being applied some months ago.

However, the middle class population has been hit by the war and war damage, as well as the economic transition, and can hardly provide for the renewal of dilapidated buildings in which they now own flats. Such financial burdain will force numerous owners to sell their flats and move into smaller ones. Owners of flats in centres of cities, where the buildings are predominantly old and require more maintenance, will probably try to move to newer parts of the city. In all, after fifty years, housing has again become an economic category.

3 Review of the Housing Space in Croatia

The age of the housing space in Croatia is relatively high, with over 36% of the total space being built before 1960. Of this, 23% were built before 1945, and the rest during the 15 post-war years. The quality of these latter ones was significantly inferior, creating additional maintenance problems.

Table 1. Age structure of housing space in Croatia

CONSTRUCTION YEAR	NUMBER OF FLATS	[%]
do 1918	223,004	14.2
1919-1945	147,769	9.5
1946-1960	199,697	12.7
1961-1970	329,937	20.9
1971-1980	379,876	24.3
1981-1985	156,630	9.9
after 1985	132,812	8.5
Total	1,575,644	100

Source: The 1996 Statistical Yearbook of the Republic of Croatia

As the table shows, over 63% of the total housing space in Croatia has been built during the last 35 years [5]. It was normal in the socialist system for the state to build new housing blocks in new city districts, while systematically neglecting the existing housing space composed of old, pre-war patrician buildings for which maintenance there was no funds. They were occupied by either the owners of flats or the right-to-use tenants and such flats were maintained depending on individual needs, ambitions or financial strength, but without any obligation from the tenants.

Although neglected and in poor condition, these buildings have to be preserved for their historical, cultural and architectural value, while ensuring the basic requirements for safe and quality usage.

Zagreb became a free royal city in XIII century and has as rich history. Its old core has numerous baroque buildings from XVI and XVII century, making the situation in Zagreb more complex. This is the reason that motivated the authors to look for conditions for the application of sustainable maintenance on the Zagreb example.

3.1 The Zagreb Case

We shall start the analysis of the building maintenance problem in Croatia using the example of Zagreb, its capital. In total in 1994. there were 294,184 flats in Zagreb.Their age is relatively high with over 71,201 (24.2 %) of the total being built before 1945 (22,534 flats (8.8 %) being built before 1918). In last 25 years in Zagreb only 24.7 % of total housing space was built, mostly in new Districts like Novi Zagreb. The table below shows the different structure of expenses for maintenance of buildings according to age.

Table 2: The structure of maintenance costs of building according to their age

Housing buildings	Large and high housing buildings	Housing buildings with up to 4 storeys with over 20 flats	Small buildings (cultural heritage)
Age, years	20-30	5-15	70-l 50
Quality of housing	poor	good to very good	average
Intensity of maintenance	low	medium	relatively high
Maintenance expenses	relatively low	medium	high
Maintenance			
Emergency repairs, %	30	30	5
Services & inspections	10	4	1
Small repairs, %	25	40	15
Large repairs, %	25	20	75
Removal of damage, %	10	6	4

For our research the sample consisted buildings in three districts – Centar, Novi Zagreb, and Tresnjevka – which are historically and architecturally very different. All three districts represent a very homogeneous sample, and cover three important groups of housing buildings in Croatia, and can serve as a model for setting priorities in sustainable maintenance.

Table 3. General analysis of maintenance of housing buildings

DISTRICT	CENTAR	NOVI ZAGREB	TRESNJEVKA
Population	51.810	127.645	125,910
Number of buildings	2.026	1.691	1,310
Number of flats	12,000	3 1,000	35,000
Living area, m^2	972,480	2,0 15,000	2,275,000
Annual maintenance costs, US$	4,563,000	2,526,700	2,099,200
Age	70 - 150	5 - 40	20 - 30
Average costs, US$/$m^2$	4.7	1.3	0.9
Average costs US$/head	88.1	19.8	16.7

Source: Archives of the Municipal Housing Authorities for 1994

The whole of the Centar District is a protected city centre, with the majority of buildings from the second half of XIX century or early XX century. The buildings normally have four storeys, with retail outlets or office space in the groundfloor. Structurally, the buildings consist of walls in masonry, and floors of timber beams. The roofs are pitched with timber structure and tiles. Due to the unresolved maintenance system in the former system their state is relatively poor.

The Trešnjevka District is divided into two parts. The older part, with buildings 25 to 30 years old, consists of buildings with 10 to 20 flats each. Structurally, the buildings have a reinforced concrete (RC) framework with flat roofs unfit for walking. Most of the maintenance costs is spent on the roofs. The newer part emerged some ten years ago, with four-storey buildings with RC walls and floor slabs and pitched roofs.

There was no significant investment on maintenance in this newer western part of the district. Novi Zagreb is entirely made of large housing blocks and skyscrapers erected during the period of expansion of housing construction from 1960 to 1980. Buildings have an RC framework and flat roofs.

Table 4. Review of expenses for maintenance in three Zagreb districts

TYPE OF WORK	CENTAR [%]	TRESNJEVKA [%]	NOVI ZAGREB [%]
Emergency repairs	6.6	39.0	32.0
Services and inspections	0.8	4.0	8.3
Small repairs	13.7	26.4	22.5
Large repairs	78.0	30.5	26.4
Damage repairs	0.3	0.1	10.6
War damage	0.6	0	0.2
TOTAL [%] us $	100 4,563,000	100 2,526,700	100 2,099,200

Source: Archives of the Municipal Housing Authorities for 1994

It is clear from the structure of expenses that the Novi Zagreb and Tresnjevka districts have high expenditures for emergency interventions, while the expenses for large repairs and reconstructions make a minor part of the total expenses for maintenance. Such a structure of expenses is very unfavourable and in the long term drastically increases maintenance costs.

The structure of expenses in the Centar District shows that most of the expenses go for large repairs, which in 1994 amounted US$3.5 mil. Such a structure reflects an increased care for the old city centre, but is still insufficient. For instance, it was planned to spend US$1.8 mil. on the renewal of facades, but due to lack of resources only US$540,000 was spent.

Typical large repairs include facades, replacement of old water supply and sewerage installations, roof repairs, internal renewal of staircases, introduction of central heating, repair of structural elements etc.

According to data from 1994, US$2.3 mil. was spent on the maintenance of housing buildings in the Tresnjevka District. The highest percentage of this was spent on emergency interventions for the repair of water supply and sewerage, central heating, elevators, roof repair, and structural repair, particularly bearing walls.

Data given in Table 3 on the maintenance of housing space in the Novi Zagreb District show that most of the funds were spent on emergency interventions and large repairs. This points to the fact that insufficient attention is paid to regular maintenance, which results in frequent occurrence of large damage.

In general, of the planned funds most expenses went for emergency interventions on water supply, sewerage and central heating installations, then for the repair of roofs and elevators.

The given data confirms the fact that the cause of the poor condition the buildings in Novi Zagreb are in is not only the lack of regular maintenance but also due to the inferior design, constrution and maintenance of installations, poorly designed and constructed flat roofs, as well as poor quality and age of elevators.

The main requirement of rational maintenance implies comprehensive reconstruction after which only regular maintenance would be required. Investments in such reconstructions, particularly in parts of installations and flat roofs, would pay back through savings in regular and emergency maintenance.

4 Model for Setting Priorities for Sustainable Maintenance

To set priorities in the maintenance of buildings, with the principle of sustainable maintenance in mind, one should define criteria for the valuation of individual works needed and decision making. Each criterion weighs each element of maintenance, and a total figure defines priorities. These criteria vary from country to country and are subject to continuous scientific research and upgrading.

Historical, aesthetic, cultural, material, and functional values of a building, its age and other elements are all criteria which should be included in any decision-making model for priorities in maintenance. All models are based on a consistent and objective valuation of set criteria and on the formation of an index defining priorities in maintenance. The more criteria taken into consideration, the more substance the decision made has.

Research to date has resulted in the formulation of several models for setting priorities in maintenance of buildings.

One of the most widely known models is the attributive approach to setting priorities in maintenance. This model was developed in 1993 at the University of West England, UK. The authors were Prof. Alan Spedding, prof. Roy Holmes and Dr. Geoffrey Shen. Their starting point was a comprehensive study of the existing state in defining maintenance priorities by local British authorities and an analysis of the priorities setting models published to date. From the practical aspect, the model is simple, and from the manager's standpoint flexible enough. The very process of making decisions is transparent enough to enable the participation of the users of buildings in defining priorities.

When defining priorities in planned maintenance, the decision makers should analyse the condition of the building from various aspects, such as technical, political, financial, social, economic, and legal. After taking into consideration the above aspects, the criteria are defined and weighing factors applied. Besides standard criteria, special criteria also occur, such as legal aspects, maintenance policy, diverse informal pressures and others. Sometimes these special criteria have more influence than the standard ones and are decisive in decision making.

Always the first step in planned maintenance of buildings is defining structural and nonstructural elements which require replacement or repair works [6]. The task on the model for defining priorities is to sequence consistently the defined maintenance works according to their overall significance. All models are based on an as consistent and objective weighing valuation of planned works as possible, and on the formation of a cumulative index which defines maintenance priorities.

Let us define *n* criteria – $C_1, C_2, \ldots, C_i, \ldots, C_n$ – and let their relative significance or relative weight be defined with $W_1, W_2, \ldots, W_i, \ldots, W_n$. If we label with j the work on the replacement or repair of a considered element, then for each criterion we can valuate this work, or the significance of this work relative to the set criterion. We shall label these values with $S_{j1}, S_{j2}, \ldots, S_{ji}, \ldots, S_{jn}$. The cumulative index, called the index of priority for work *j*, is derived applying the following simple expression:

$$I_{pj} = S_{j1} \times W_1 + S_{j2} \times W_2 + \ldots + S_{ji} \times W_i + \ldots + S_{jn} \times W_n$$

This way, each work on the maintenance of a building is valued by a single parameter, and prioritisation is carried out by simply arranging the indexes in a descending order.

A new model for sustainability of maintenance is being developed at the Faculty of Civil Engineering in Zagreb within a scientific project which is based on the above described attributive approach and is adjusted to the specifics of transition countries one of which is Croatia. When defining criteria, the specifics of Croatia as a transition country, but also a country with rich cultural and architectural heritage, were taken into consideration. Besides this, the model will attempt to consistently weigh the proposed criteria.

5 Conclusion

This paper presents three types of urban districts in Zagreb, with buildings of diverse historical, cultural and architectural value. While some buildings are in poor condition and economic parameters indicate that these could be demolished without additional consideration, other which form the old urban centre and represent the wealth of all the citizens and even country should by all means be preserved.

The problem is how to preserve the original appearance of a building, and also ensure the safety and quality of usage. Sustainable maintenance implies that the buildings are to be maintained so as to provide the people and communities with social, economic and cultural well-being without compromising the ability of future generations to meet their needs and to preserve their heritage.

No scientific research has been undertaken in Croatia to date which covers the management and maintenance of buildings. International experience in this field cannot be directly applied since each country has its own specifics in problems to be overcome by maintenance, such as the age of buildings, their initial quality, applied technology and materials and economic transition, like in Croatia, which reflects on the financial potential of the population and municipal authorities.

The problem of sustainable maintenance is itself very complex, and becomes a real challenge to scientists in transition countries that have changed the political system.

This is why it is not possible to apply directly the available knowledge on maintenance management to the Croatian case, but the existing knowledge and possibilities should be adjusted to our requirements and specific conditions.

6 References

1. Bon, R. (1995) *Global Construction,* Survey, Reading.
2. Gustafsson, S., Karlsson, B., Bertil, *S.* (1987) *Optimization of Retrofit Strategy for a Building in Order to Minimize its Life* Cycle *Cost,* CIB, Copenhagen.
3. Ashworth, A., A-Yeung, P.L.Y. (1987) *The Usefulness of Maintenance Cost Records in Life Cycle Cost Predictions,* Spon.
4. Katavic, M., Zavrski, I., Cerić, A. (1997) *Maintenance Problems in the Republic of Croatia,* Information Support for Building Economics, Salford.
5. Katavic, M. (1994) *Analysis of Conditions in Construction and Building Materials Industry in the Republic of Croatia* (in Croatian), Ministry of Counstruction RH, Zagreb.
6. Katavic, M., Zavrski, I., Cerić, A. (1997) *Information Systems in Building Maintenance,* Information Systems '97, Varaždin.

Sustainable Building Organisation

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Abstract

Sustainable Development and Sustainable Building is mainly a question of (human) environmentally-conscious Organisation and Management.
Criteria are needed in order to capture the best practices in the field. Therefore we developed modells and methods, which help to choose the most adequate practices.
Invention of key research activities can be brought up by screening the current problems in the light of the Meta-Modell Integral Bio-logical Architecture which at the same time will help to identify the gaps in the field of research.
By the use of the Method Holistic Participation - MHP it is possible and stimulating to work multi-and interdisciplinary.
With the help of MHP consensus can be supported systematically and even reached in order to find a research agenda with those priorities, which have a high probability to be able to contribute essentially to Sustainable Development and Sustainable Building.
Managing this task in the frame of one of the most urgent world problems - Building in its nowadays way as a danger for Environment and - perhaps paradoxical - even for Humankind as well, it is at least strongly connected to the Legal and Procurement Practises, which similarly - as described above - can be approached, especially by the MHP concerning the Aspects of Conflict and Dispute Resolutions.
Since a certain Indoor Climate is one of main reasons to build it, will be most conditional to link Management with the demands of and for a healthy Indoor Environment, which finally needs also a healthy Outdoor Environment. For the balance between them the Strategy for Optimising can be applied. But Materials and Technologies have to be choosen properly. For this a special Matrix can be offered which at least as a rule of thumb can function as a further organisation aid.
Together with a view on the flanking subjects Management and Organisation can effectfully be runned by globally thinking while locally acting and planning on short as well as longterm, as the most important demands for reaching the aim of Sustainability.

Keywords: Methods, modells, optimising, invention, consensus

Sustainable Building Organisation

Sustainable Development and Sustainable Building is mainly a question of (human) environmentally-conscious Organisation and Management.

Criteria are needed in order to capture the best practices in the field. Therefore we developed modells and methods, which help to choose the most adequate practices. Invention of key research activities can be brought up by screening the current problems in the light of the Meta-Modell Integral Bio-logical Architecture which at the same time will help to identify the gaps in the field of research.

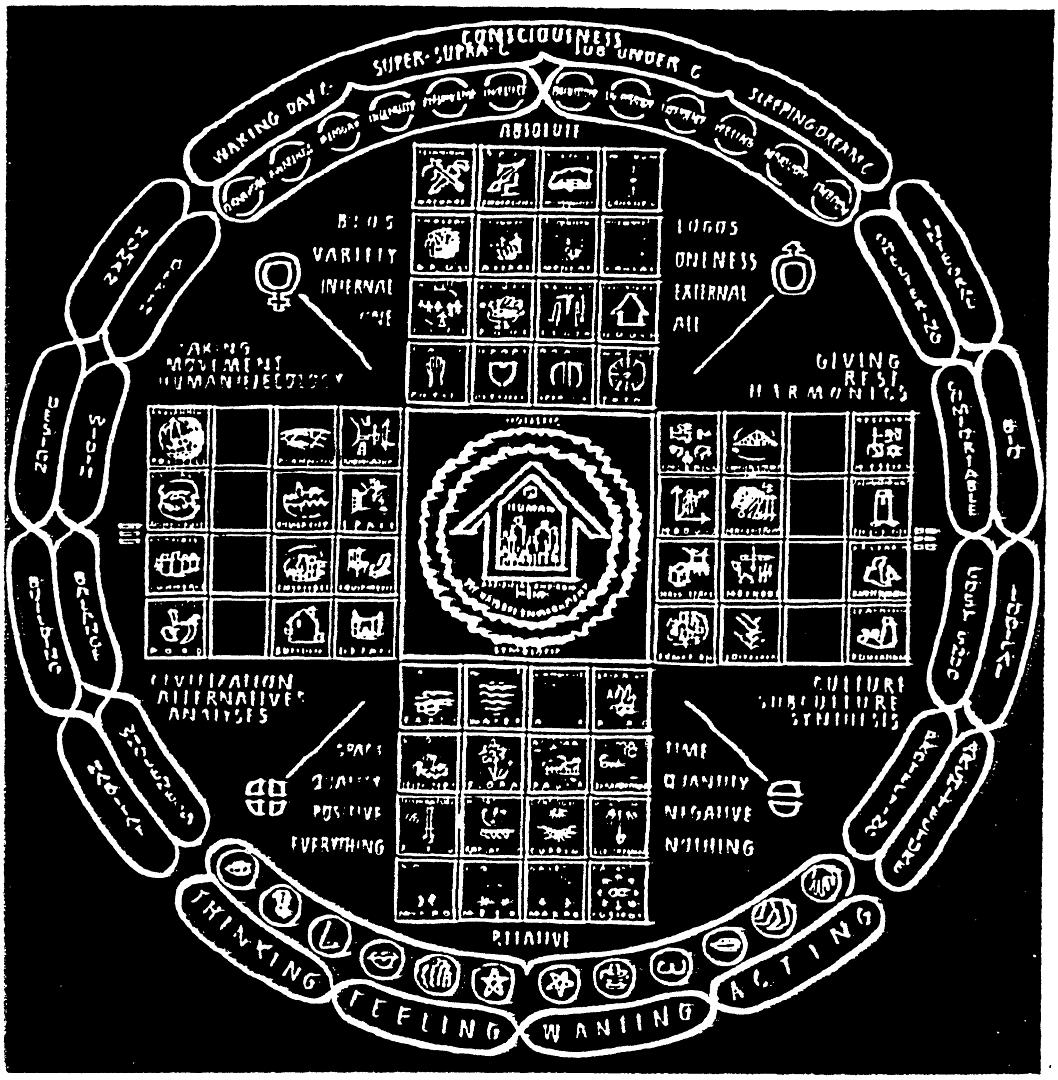

Figure 1
The Meta Model Integral Bio-Logical Architecture shows the factors and their interrelationship concerning Building between Humankind and Nature.

By the use of the Method Holistic Participation - MHP it is possible and stimulating to work multi-and interdisciplinary.
With the help of MHP consensus can be supported systematically and even reached in order to find a research agenda with those priorities, which have a high probability to be able to contribute essentially to Sustainable Development and Sustainable Building.

HOLISTIC

PARTICIPATION

Figure 2
The Logo of the Method Holistic Participation symbolizing the rol play's of co-operating (expert) persons or teams, who in a weaving rotation - even starting with opposing opinions - can come to consensus.

Managing this task in the frame of one of the most urgent world problems - Building in its nowadays way as a danger for Environment and - perhaps paradoxical - even for Humankind as well, it is at least strongly connected to the Legal and Procurement Practises, which similarly - as described above - can be approached, especially by the MHP concerning the Aspects of Conflict and Dispute Resolutions.*

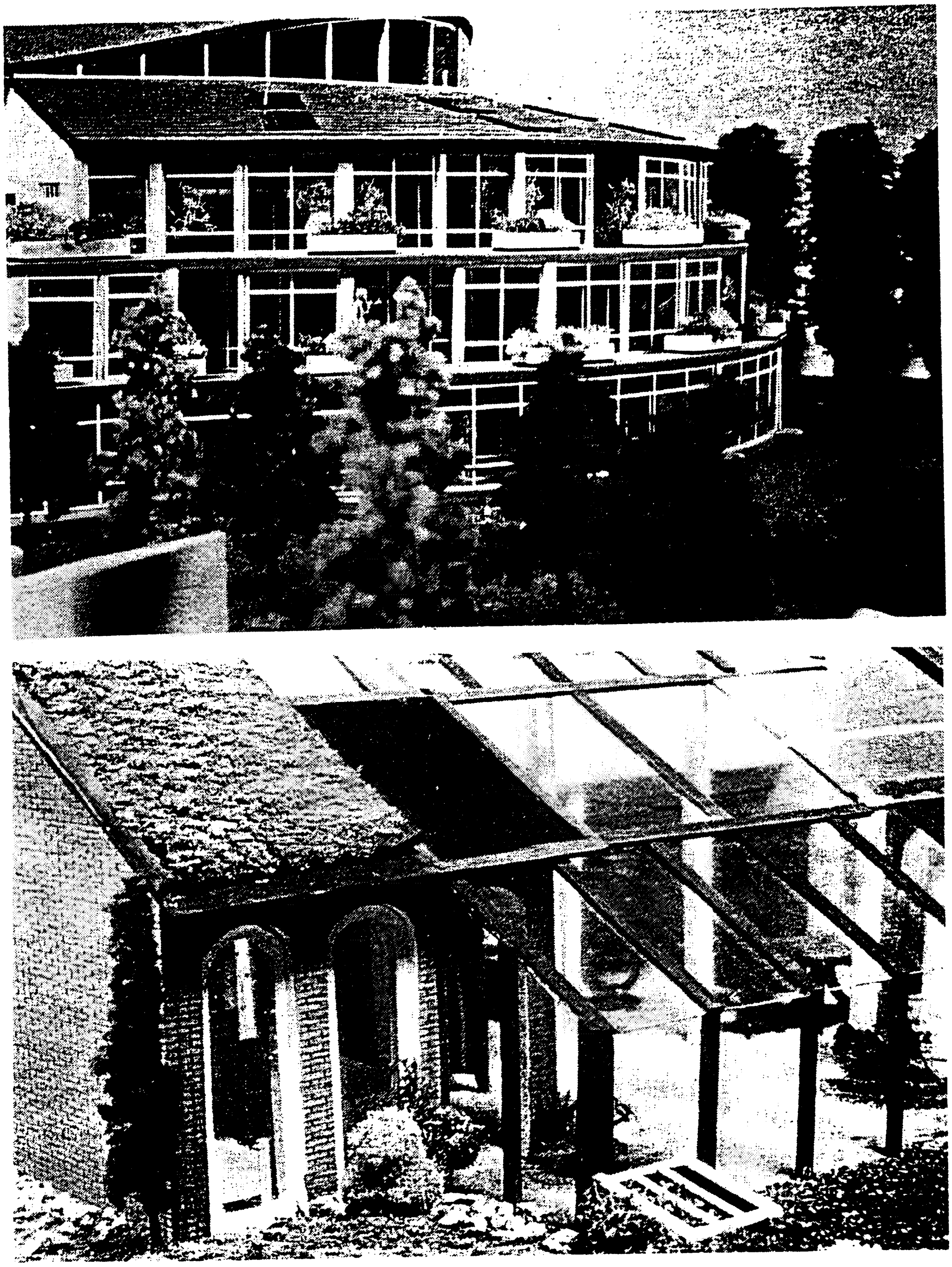

Figure 3
Attempts towards Sustainable Building: Various examples of human-ecologically, healthy and environmentally-conscious holistic concepts, realised in projects.

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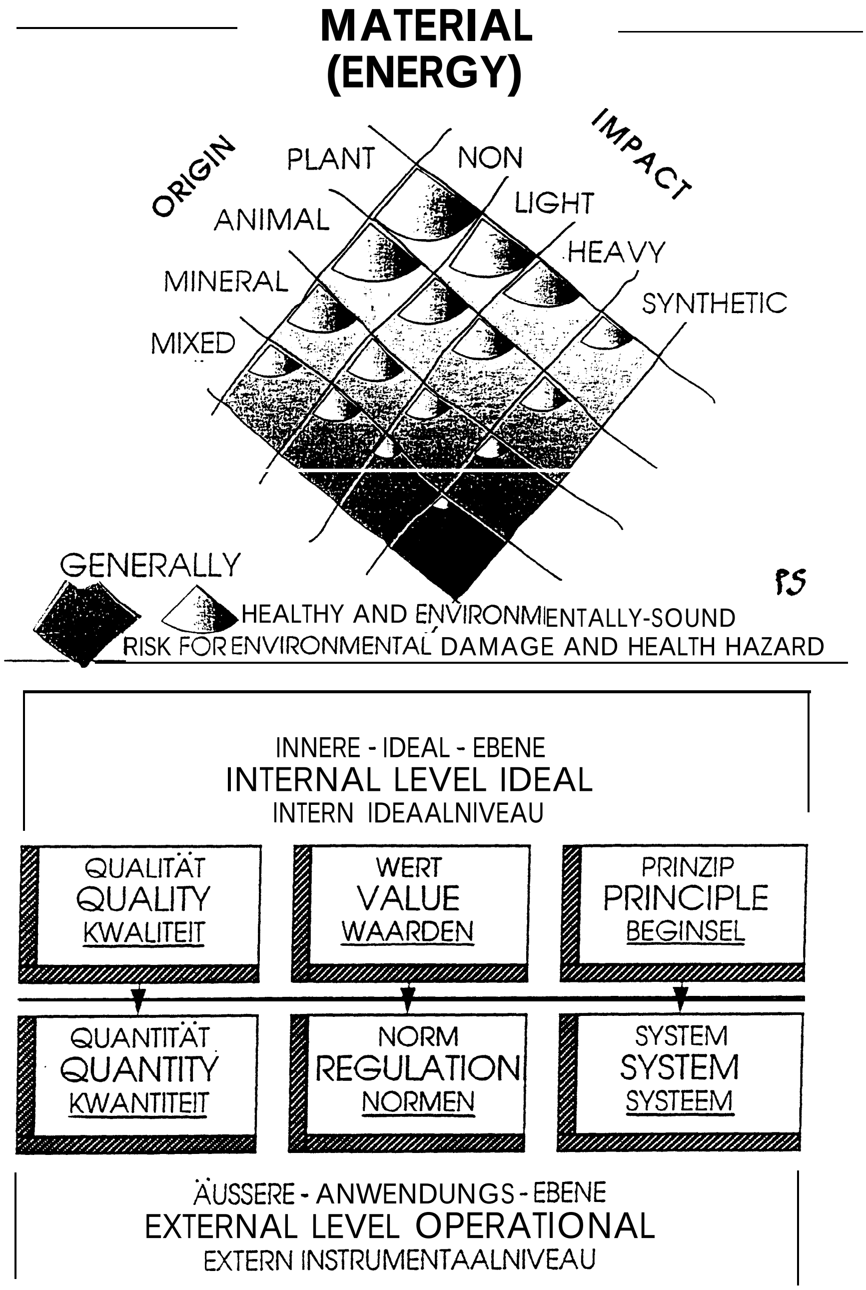

Figure 4
The evaluation of the impact of the use of materials (and energies) on health and environment is already roughly possible by the means of the Instrument Material and Energy Choice Matrix. The scientific approach towards the discussed problems should be supported by Principles, Values and Qualities.

References

- Schmid, P. *(1986) Bio-Logische Baukonstruktion, Wege zu einer integralen Bau- und Ausbautechnik,* Mensch- und Umweltorientierte Hochbaukunde, Atlas einer human-ökologischen Baukonstruktionslehre, Verlagsges. R. Miiller, Köln.
- Schmid, P. *(1986) The Instrument ☐↗ an Integral bio-logical Architecture, designaids for housing and built environment,* 1 lth World Congress of Sociology, New Delhi, India.
- Schmid, P. (1986) *Holistic and Bio-Logical Light Weight Structures for Healthy and Individual Housing* 1st international conference on lightweight structures in architecture, Sidney.
- Schmid, P. (1986) *New Building Concepts on Totality-Proces-Detail - Ecological Architecture* (SHE), Congres of the Society for Human Ecology 'Human Ecology: Research and Applications', Bar Harbor, Maine, U.S.A.
- Schmid, P. (1987) *Integral Bio-logical Architecture,* 13. Kongress der Internationalen Gesellschaft zur Erforschung von Zivilisationskrankheiten und Umwelt (SIRMCE), Lausanne.
- Schmid, P. (1987) *The Gaia Building System,* International Conference on the Design and Construction of Non-Conventional Structures '87, London.
- Schmid, P. (1988) *Architecture-Ecology-Health,* 3rd International Conference of the Society for Human Ecology - SHE - San Francisco, U.S.A.
- Schmid, P. (1989) *Building on Peace,* Key-note paper, International Prague Assembly of architects, planners and designers for professional actions against ecological disaster, homelessness and armament race, Palace of Culture Prague, CSFR.
- TUE, IFAM (1990) *Minimalisering van de Milieubelasting in de Woningbouw,* onderzoekrapport, i.o.v. Stichting Milieubewustzijn, Hilversum, Amsterdam - Eindhoven.
- Schmid, P., Haas, M. (1990) *Bio-logisch bouwen en wonen, gezond voor mens en milieu,* A&h-Hermes, Deventer.
- Schmid, P. (1991) *House of Another Future,* 9th International Svedala Symposium on Ecological Design, Svedala, Sweden.
- Schmid, P. (1992) *Integrated Development (Gaia Building Systems), European Cities: Growth and Decline,* International Conference in The Netherlands, Den Haag.
- Schmid, P. (1994) *Sustainability and Building,* CIB Conference, U.S.A.
- Schmid, P. (1995) *The World a Green School for Everybody,* Environmental education for the whole society, A contribution towards sustainable environment, International Conference Environmental Issues Education and Training, University of Mateja Bela, Banska Bystrica, Slovak Republic.
- Schmid, P. (1995) *Sustainable Architecture,* International Symposium 'A Vision of architecture of the 2000's: Green and glocal architecture' on behalf of the 50th anniversary of the AIK-Architectural Institute of Korea, Seoul, Korea.
- Schmid, P. (1996) *The Different Houses of the Nations on one World, The common Sustainable Habitat reflected in the Joint,* XXIVth IAHS World Housing Congress, Ankara, Turkey.
- Schmid, P., P'al, G., Liddell, H., Halliday, S. (1997) *Green Arrows from Gaia International,* Sustainable Architecture in Auckland and Wellington, New-Zealand.
- Schmid, P. (1997) *Environmentally-sound Eastern European Eco-Housing (EEEE),* IAHS World Congress on European Housing, Sinaia, Roemenië.
- Schmid, P., Liddell, H. (in preparation) *An Introduction to Ecological Design.*

Tentative application of the ECE Compendium of Modet Provisions for Building Regulations

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Abstract :

The ONU ECE Compendium of Model Provisons for Building Regulations issued in 1996 proposes for the first time in the history of regulations a chapter 4b dealing with “requirements for a building compatible with sustainable development”.

It proposes to characterize materials used in building by indexes of :

Renewability of the resources
Difficulty in disposing of the wastes
Recyclability

In a French study about building briefs, written in terms of requirements, a tentative application of this characterization has been made.

The characterization of various materials using these indexes gives rise to difficulties among the producers.

Are we prepared to face these ?

A. Presentation of the problem

1. Consumption of building materials create a large part of the problem of sustainable development because the mass of these consumed materials is enormous.

In what follows, we will put aside the public works, specially important in agregates consumption. We will also not take into account the warmhouse effect of heating or air conditionning devices.

For example, the figures of the yearly consumptions of some main building materials are :

Ciment : 1.2 billion tons
Timber : 3 billion cubic meters

These are today’s figures, corresponding to a human population of less than 6 billion people, among them less than 1 billion are members of the affluent society.

When the world population will reach the 10 billions, and if the standard of life of the poor significantly increases, these figures should be increased about four times.

The impact of building product consumption when building, and of building refuses when demolishing is thus really considerable. What creates a great concern.

2. To be efficient when dealing with such a problem it is necessary to avoid, as far as possible, gossips, but :

a) to use figured characteristics resulting of measures or classifications of the parameters contributing to the risks of endangering the sustainable development.

b) to deal with the various aspects of the problem as a whole, non foncussing on such or such aspect as demolition refuses disposal, or contribution to the warmhouse effect - because when using a material affects may be caused at all the facets of the sustainable development at the same time.

c) to try to propose solutions for improving the situation, which is very difficult, but unavoidable if efficiency is seeked. Putting in practice these soltutions may be the fact of "virtuous" clients and building people, conscious of the importance of the problem or of reglementary authorities, today at the national or regional level.

B.1.. .In the spirit of what preceeds, the author, at the demand of the Human Settlement Committee of the UN Economic Commission for Europe proposed a supplementary chapter to the ECE Compendium of Model Provions for Buiding Regulations 1991 edition :

Chapter 4.2 - Requirements for a building compatible with sustainable development,

which has been accepted by the Committee and published by the UN Press in 1996.

This chapter dealt with the characterization of the materials in consideration of :

their renewability

their recyclability

the biodegradability and non noxiousness of demolition waste.

In the year 1996, I had the opportunity to try to make application of these dispositions for ADEME, the French Agency for the environment and energy saving.

It was the opportunity of adding two other characteristics to those considered :

- The consumption of energy at the production
- The amount of energy recuperable at the combustion after demolition.

We also proposed classes for every character. Thus we came to the charectarisation guide below.

Two things at least are clear :

First, the limit between classes comprises a large part of arbitrary : in fact, as we will see below, it is at the application of the grid to a set of materials that the frontiers between classes will be set down.

Second, the classification of a material is not absolute, but depends upon national or local parameters :

e.g. Timber is renewable if measures are taken for reforesting,
Glass is recyclable if collect systems of waste of glass are organized,
etc.

Thus the grid of classification is variable in space and time.
But at a given time and place it is usable

B.2 The RCD PE grid of characterization

a) R - the renewability

3 classes are proposed :

R1 : Material complety renewable
It means : whose original resources is renewable
e.g. - Timber and wood when reforesting

R2 : Material partially renewable, e.g. gypsum plaster pannels with a wicker reinforcement

R3 Non renewable : practically any material except vegetable.

b) C for Recyclability

Cl Recyclable to the same product - e.g. - steel, aluminium

C2 Recyclable to another product, e;g. glass (from glass panels to bottles), concrete from structural concrete to road agregates

C3 Non recyclable - e.g. Polyester, reinforced concrete.

c) D for bio-Degradability of the products after demolition. For this character, what appears possible is simply to create a class D1: biodegrable and another but cut in two :

D2 Non biodegradable, non noxious

D3 Non biodegradable , noxious.

Examples of D1 , could be timber, textiles, some plastics.
Examples of D2 - stony or ceramic materials
Examples of D3 - Asbest cement, quick silver which shoud be excluded from the use and free waste disposal.

d) E - What is in cause here is the energy of production

The concern is not the warmhouse effect, but the consumption of limited natural resources.

Some production processes may be accomplished only with mineral or vegetable fuels. Others like steel fusion may be done using electricity which as in France, may be largely nuclear. This distinction should be done, but has not been undertaken here.

Three E classes are proposed :

El - Energy less than 2000kW per ton, e.g. timber, natural textiles

E.2- Energy between 2000kW and 5000kW per ton. Example given : concrete and reinforced concrete, gypsum plaster, ceramics.

E.3- More than 5000kW. e.g. ashphalts, some plastics.

It is clear that the classification is too rough and that class E2 should be split up.

e) E for energy produced by the combustion of wastes.

In this field 3 classes are proposed :

El Combustible without noxious effects of the combustion products, e.g. timber, textiles, some plastics.

E2 Not combustible, e.g. Stoneous, ceramics.

E3 Combustible with production of noxious gasses e.g. PVC, PU.

It is clear that this classification is in relation more with pollution than energy. The point should probably be reconsidered.

B3 At the end using the RCD PE grid, or better, with an improved grid of the same spirit, we have the means to produce a profile for any material.

Without being from far exhaustive, we will give here some examples of RCD PE profiles :

Steel : R3, Cl, D2, P2, E2

Comment : The fact that steel is D2 - practically non degradable, is compensated by the fact that it is from a long time recyclable. This proves that a character should not be appreciated on its own.

Glass presents the same profile as steel.

Timber's profile is : Rl, C2, D1 ,El ,P1

Comment - The fact for timber to be D1: biodegradable, is not important since it is C2 if the necessary dispositions for recycling are taken.

As for plain concrete the profile is :R3,C2,D2,E2,P2.

To get an end to these profile characteristics, we should note that, as generally in matters of profiles, it is not possible to condensate the profilen a global note, as a consequence of the diversity of the relative importance that may be given to the various characters at different places and times.

C. What to do for the sake of sustainable development ?

cl. "Virtuous" clients may use the profile to determine in their briefs which materials they oppose, they recommend, or compell.

And in the same way the building authorities may impose or refuse materials by the way of regulations.

But our experience is that when a lobby of producers of one material becomes conscious that its profile is apparently less favorable from those of competiting other materials, say plastics and wood in floor coverings, it shows a strong reaction that will probably impeed any public action, if not the diffusion of the profiles.

So the way of coercition seems to be unfavorable.

c2 Things being as they are, the best attitude may be to incite the improvement of the profile of a material, seemingly defavorized :

It is possible to act in many ways :

R. To reduce the consumption of non renewable materials using better building systems, better calculation methods, better combined use of various materials e.g. steel and concrete in structures.

To take measures to make renewability a reality : e.g. replanting forests.

C. To develop recyclability schemes, e.g. In Switzerland concrete is recyclable at the rate of 2/3.

E. Modernization of production may lead to drastic cuts in energy consumption at production. e.g. bricks and roof tiles.

To push for these measures, the menace of coercition could be maintained at the horizon.

But something should remain clear :

Today, building is fundamentally too expensive.

Measures in favor of sustainable development will not be accepted if they bring about cost rises. e.g. to use recyclable materials should lead to cost savings and not to the contrary.

Towards a more sustainable development : a model for the building sector production

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Abstract
Nexus is an intelligent environmental model, developped by AUXIRBAT, whose research team is linked to several others belonging to the CNRS in France.
It has been used to build various scenarios whose purpose is to identify the degree of sustainability of different paths of building sector development.
In first place, it was noticed that the concept of sustainability could not refer directly to the building sector, for the reason that specific and scarcity problems generated by buildings are not very large, and also because the main problems for the future generation are the land-use aspect and the energy consumption, which are two items involving many other sectors.
Nevertheless, a methodological approach has been developped that shows on a long-term range a great difference in the impact of a « let things go their own way » scenario, and an interventionist scenario through the authorities action, either in regulations forms or by tax and incitative mortgages.
For the previous aspects described, Nexus Model provides data that are able to assess the cost-benefit of each considered path of the development of the building sector.
Keywords : Building sector, modelling, Sustainable development.

Main text

Introduction : Building crisis and sustainable development

Building sector and particularly housing sector in France have been passing through a crisis which origins go back to the end of 70's.
Until1 this date, stimulated by an important demand and helped by negative interest rates, building sector had reached unequalled levels in France (around 500 000 buildings a year started to be built). The delay -accrued between the two wars and strongly increased by the destructions of 2nd world war and demography evolution (((baby boom), rural exodus, immigration...) - had indeed to be cleared up.

Most of the needs were satisfied so that it seems normal that building rythms had come back to lower figures.
That impulse seems besides to be increased by another structural factor that contribute to the same phenomenon : the increase of bying cost for final buyer which brought a break in solvent demand.
The result of this situation is a stagnation and even a recession in current francs in all the building activity (-1,7 % in 1996) and the maintenance at a very low level of new buildings : less than 300 000 buildings and 15 millions m^2 started to be built for tertiary sector).

Even if the maintenance and the renovation activity have taken over the new building construction to maintain the activity of the sector (it represents now more than half of its activity), the drop in new buildings construction leads to an insufficient renewal of the total number of buildings. This brings local shortage situations and generates a wrong adjustment to the demand. The actual level of new construction, more particularly in social renting building sector, will not be able to provide durably acceptable life conditions for all the population, with the following consequences :

- more and more people will be excluded from decent housing owing to the lack of resources.
- as a consequence of the insufficient renewal of the number of buildings, technically and socially obsolete housing areas will remain, interfering with the modernisation of urban infrastructures.
- the lack of fluidity of the total number of buildings will not enable a sufficient mobility.

In front of this relatively pessimistic established fact, we wonder what could be the opportunity of the application of the concept of ((sustainable development)) to building sector.
Concerning this debate, the ((prospective approach>>, -as it enables the analysis of the margins of manoeuvre and the consequences of a «let things go their own way» policy on the future of the sector and its impact on the environment-, represents an assistance tool for decision-taking, very important help for the implementation of a ((sustainable development)) policy applied to building sector and more specifically to housing.
The NEXUS Habitat model, developped by Auxirbat within the Research Group OÏKIA of the CNRS[1], enables to detail by a quantitative way this prospective thought.

1 Scenario of possible evolution of building sector :

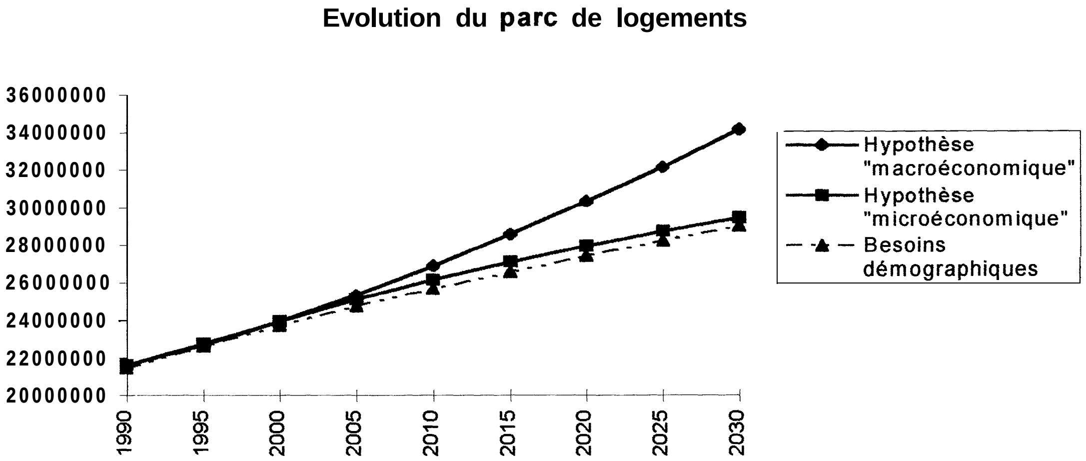
The building sector is very sensitive to greet macroeconomical parameters variations :

- the demand is a function of the income evolution of households, which also depends on the evolution of national wealth.
- real interest rates determine for a large part the loaning capacity of households and prime contractors.

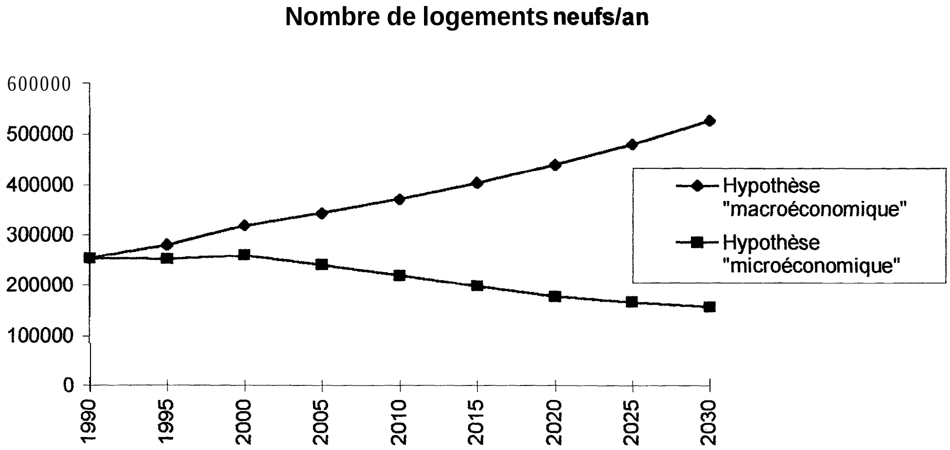
- the size and the orientation of public aid, which depends for the most on public finance, conditions the access to housing for the poorest populations.
- the evolution of relative productivity, which is a function of the technological and organisational innovative capacity of the sector, and which determines the evolution of construction costs.

The use of «Nexus Habitat)) model had enabled to outline the tendencies of the sector according to the values assigned to every proceeding variables within the scope of three contrasted scenarios.
The central question in a «let things go their own way» scenario in the environmental sphere is to determine the level that could durably reach the construction of new buildings within a middling growth economy, where most of primary needs in housing are satisfied.
To answer this question is difficult, because the results obtained by the modelisation are different according to the major macro-economical equilibriums and -on the opposite- to the behaviour of micro-economical actors and particularly households.

Graph 1



Graph 2



On the whole, the «let things go their own way» scenario shows us two images of the future in which the productivity profits and the qualification of labor would take a great place.

The first image is the one of a sector that finds its dynamism again, keeps on mobilizing a relevant part of investment, and increases built areas offered to the population, carrying along a more and more important occupation of the space, together with an increase of the agressions on environment, that are limitated but true.

The second image, more malthusian, is the one of a sector to maturity which continues to keep focus on the maintenance of a huge existing estate.

The improvement of life conditions here doesn't follow the increase of areas : it follows the improvement of the existing number of buildings.

Besides that, all the available area by inhabitant does not decrease comparing to 1990.

Nevertheless, this second image, almost more respectable for the environment as less «productivistic», should not bring a more important recession (in terms of turnover and employment) than the present one[2]. On the other hand, it presents the disadvantage to offer little margin of liberty to solve crucial problems such as poorest people housing, the elimination of ghettos, necessary evolution of urban transport...

From the energy consumption point of view, the two approachs are equal and show that in absence of measures, it will materially increase, mostly because of the increase of electricity consumption.

Table 1 : Distribution of energy consumption 2020-2030 (in millions of TOE)

<table>
<tr><th></th><th>1995</th><th colspan="3">2020</th><th colspan="2">2030</th></tr>
<tr><th></th><th></th><th>(1)</th><th>(2)</th><th>(3)</th><th>(1)</th><th>(2)</th></tr>
<tr><td>Electricity</td><td>25,5</td><td>38,6</td><td>41,6</td><td>37,6</td><td>51,6</td><td>43</td></tr>
<tr><td>Petroleum Products</td><td rowspan="2">24,6</td><td rowspan="2">25,1</td><td>12,5</td><td>12,7</td><td>12,4</td><td>12,8</td></tr>
<tr><td>Gas</td><td>14,7</td><td>13,2</td><td>17</td><td>14,1</td></tr>
<tr><td>Coal</td><td>4 6</td><td>10,8</td><td>18,</td><td>19,</td><td>17,</td><td>19,</td></tr>
<tr><td>wood</td><td>54,7</td><td>74,5</td><td>43</td><td>46,</td><td>4</td><td>45</td></tr>
<tr><td>Total</td><td></td><td></td><td>74,9</td><td>70</td><td>86,7</td><td>783,</td></tr>
</table>

(1) datas producted by MEDEE by the « Commissariat au Plan »
(2) datas producted by NEXUS - macro-economical approach
(3) datas producted by NEXUS - micro-economical approach

2 The normative scenario :

About the new construction rythm, it seems' difficult to go beyond the preceding micro-economical hypothesis.
In fact, this hypothesis leads only to maintain the lodging conditions of the 90's, with a renewal rate of the number of building of 3 %, that is to say a building duration of life of more than 3 centuries[3].
Most of the political measures that characterize this scenario would rather aim at improving the working of existing number of building.
These measures would mostly deal with the comfort and the health of the occupants, the renovation of frontages which interface part with city is very important, the inexpensive equipments in water (which cost should increase by 10 to 50 % to 2005), the domestic energy consumption and the associated carbon emissions.
The expected results are significative compared to the «let things go their own way» scenario since in the aggregate the energy savings in the residential sector could raise above 15 MTOE/year, while carbon emissions should be stopped at 70 % of the level of 1995.

Table 2 : Saving potential for each measure (in Millions of TOE)

	"hypot.basse"	norme/1	norme/2	croiss. seule	clim/20%	écon	eco+subst	isol/U1	isol/Uo
CE	43,01	-5,15	-5,15	1,03	4,12	-0,35	9,17	-0,45	-0,34
CP	12,80	-1,77	-1,17	0,00	0,00	-0,98	-5,50	-0,09	-0,52
CG	14,13	-1,93	-1,42	0,00	0,00	-0,65	-4,23	-0,56	-0,30
CC	1,84	0,00	0,00	0,00	0,00	-0 18	-1,50	0 00	-0,09
CB	4,50	0,00	0 00	0,00	0,00	0,00	0,05	0,00	-0,24
CS	0,04	0,00	0,00	0 00	0,00	0,00	0,00	0,00	0,00
CTOT	*76,32*	*-8,85*	*-7,73*	*1,03*	*4,12*	*-2,16*	*-2,01*	*-1,10*	*-1,49*
CEém	4,65	-0,56	-0,56	0,11	0,45	-0,04	3 80	-0,05	-0,04
CPém	11,31	-1,56	-1,03	0 00	0,00	-0 87	-4,85	-0,08	-0,46
CGém	9,04	-1,24	-0,91	0 00	0,00	-0,41	-2,71	-0,36	-0,19
CCém	1,99	0,00	0,00	0,00	0,00	-0,20	-1,62	0,00	-0,10
CBém	0,00	0,00	0 00	0,00	0,00	0 00	0,00	0,00	0,00
CSém	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
CTOTém	*26,99*	*-3,35*	*-2,49*	*0,11*	*0,45*	*-1,52*	*-5,38*	*-0,49*	*-0,79*

3 The flexible scenario :

The previous scenario has the advantage of limiting to maximum the pression on environment, but represents the disadvantage of increasing the inflexibilities of the construction sector and of encouraging the stagnation of economy.
Compatible with a financial disengagement of the Nation -almost complete in the sector-, it doesn’t use the margins of manoeuvre thus enabled.
The major and structurant idea of the flexible scenario is to use this financial capacity to give a more dynamic and flexible content to the previous scenario.
All aids together, the intervention of the State on the sector is around 120-billions in the «let things go their own way» scenario, amount that should be reduced to around 30-billions in the normative scenario[4] .
The reorientation of the SO-billions difference between the two scenarios could be useful to finance 4 great projects :

- a substantial support to innovation, with the implementation of Research and Development programs within the framework of a public/private partnership. These programs could fit into technological field -with the objective of a drastic decrease in costs without deterioration in quality- and into socio-economy field, with the improvement of demand knowledge and of its potential evolution.
- a renewal policy of the existing buildings, specially by the destruction of poor-quality housing with serious social problems (particularly acurate in the new residential areas consisting of large blocks of flats, built less than 40 years ago).
- the reorientation of social housing to the less financially solvent categories.
- the renovation of infrastructures and of the urban organization that can be done thanks to the faster renewal of the existing buildings.

The main advantage of this scenario from a ((sustainable development)) point of view, is to increase liberty margins for the future by the mere fact of a more important dynamism of the buildings population, with almost the same level of negative impacts on environment as in the previous scenario.

Conclusions :

At present time in France, the <(sustainable building)) approach is very « environmentalistic » and brings the sustainable development to technical and quantitative norms (acoustics and heat comfort, recycling of construction materials, recovery of river water...), that have been made compatible with the rentability objectives.
An incitative policy is preferred to implement this practice : setting of a taxation incitation system and of subventions in order to give favour to the construction of <thigh-environmental quality » buildings ; commitment for environmental plan for firms ; sensitive actions to building contractors about the ((global cost» notion.

Besides that, the margins of manoeuvre are limited, in connection with the economical restrictions applied to environmental and social action (trade conditions, improvement of national firms competitiveness, building sector support...) ; in addition, available budget resources to stimulate environmental action seems to be less and less important when public aid is requested by priority sectors (Health, Education...).
Even if we can think about a « green revival » with an important agreement for users to pay for environmental quality so as to incitate the sector to innovate in this field, this scenario still produces social and territorial segregations.
In fact, it may contribute to the development of an expensive housing, that cannot afford a lot of people, and to restrict the possibilities of State social intervention.
This trend is consequently insufficient to move the building sector towards a sustainable development.
On the other hand, the innovation directed to costs decrease becomes -owing to the margins of manoeuvre it should bring- a motor for sustainable development in building sector. Joined to public aids reorientation to make solvent a part of the demand, it could give a new stimulation to the sector, that is necessary to avoid perpetuating urban ghettos, to reorganize the structure of large blocks of flats areas without any character in the suburbs , to improve the poorest people -lodging within this framework, the revival of new buildings construction if done with a real architectural research, concerning the building as well as surroundings, that will be able to contribute to the modification of urban landscapes. This new dynamism would be also a key factor in changing space distribution of activities, reducing the «zoning» popularized by «Athens Charter)) and in establishing again the complementarity of transport means.
One could object that the search for productivity in the past was rarely undertaken with an improvement in architectural quality. That is true if the search for productivity is only made in order to reduce the costs, all process being constant : it is not the same at all if productivity profits are brought by innovation in products, process and production organization.

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[1] Nexus Habitat is a sectorial model which gives a long-term projection of the evolution of building sector and its consequences on the energy consumption. It will be integrated to a general equilibrium calculated model IMACLIM. Presently, a macroeconomical equilibrium equation guarantees the coherence of the model.

[2] Provided that the whole Economy can find new tanks of growth.

[3] However, the margin is larger in non-residential buildings, as the duration of life is around 60 years.

[4] a 20-billions aid to poorest housing and a 10-billions aid to encourage energy savings in the existing buildings.

Scenarios and visions as tools for endurable changes in sustainability in society, organisations and the built environment

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Abstract
The goal is sustainability and the means the changes that will enable it. For people to act consistently in favour of sustainability in society, organisations or in the built environment, three things are required: a technology that provides the opportunity for such action; structures/institutions in society, in organisations or in the built environment that support such action and finally a vision that supports such action by individuals willing to grab the opportunities created by different technologies. The vision guiding change activity should be rooted in the present world and in people's present set of values, as well be valid for several different futures. With the focus on sustainability in the built environment, I will show how communities and organisations can build their own scenarios and visions.
Keywords: scenario, vision, future, sustainability, built environment, organisation, change, method.

1 Introduction

For us to make changes in our behaviour, we often need a goal to guide our actions. Even when we have made changes and achieved our goal, we often fall back on our previous behaviour. In the pursuit of living in harmony with nature, we often fail to do so. Lifestyles intended to be in harmony with nature are often called the alternative lifestyles, as opposed to the more 'normal lifestyle which does not focus on it's relationship to nature. To be able to create lasting changes in sustainability in society, in organisations and in the built environment, living in harmony with nature needs to become the normal lifestyle, not the alternative one. The key to endurable change is having a clear picture where you want to go, leading you to look for signs and confirmations until you reach that point. The creation of that clear picture, also called a vision, will not only give you a direction, but also help make all the small decisions along the way easier. We can also simplify the decisions if we adopt a principle, but such a principle is not a vision. As for the early setters in North America "go west" was the principle in seeking the "Promised Land." They had a vision of this 'Promised Land', part of which was that if they went west, they would find it.

I see sustainability as a principle, not a vision. The questions are why should people follow such a principle and which vision can support it?

The reason for adopting the principle of sustainabilty today is that you will gain something tomorrow if you do. If you would gain something almost at once, the argument would be even more convincing. In the metaphor of *The Journey to the Future*, you are coming from somewhere with a certain speed and direction. Perhaps you even have a goal for your journey. The early settlers were coming from the east at the speed of a horse-drawn wagon with the "Promised Land" as their goal. They had a vision for their journey which helped them to overcome difficulties and to keep on going.

Strong motivation often comes from a vision of what we want to happen or not to happen. Today's struggle for the environmental have created a new word – sustainability. The message is that "the world will survive only if we apply sustainability to our every every action." That may be true, but is it a vision which can motivate the majority of the people in societies and organisations? I strongly believe not and the reason is that sustainability provides a negative focus on the future.

It is common knowledge in the world of sports that a team will not win if it only focusses on not losing. Winners gain strength from having a positive picture of themselves as winners. The vision which could motivate us to apply the principle of sustainability in every action must contain positive pictures of living a sustainable life and the fruits of such a life. The vision must tell us why it is better to adopt the principle of sustainability than continuing to live as we have. It must tell us what we will gain if we change our ways of doing things and look at the world with a new perspective? The majority of the people in the Scandinavian countries today would not see any immediate gain from such thinking. They probably only observe the difficulties in trying not to use the petrol consuming car or that ecological groceries cost more than the normal ones.

2 The three pillars for change

Three things are necessary to persuade people to act consistently for sustainability in society, organisations or in the built environment: a technology that provides the opportunity for such action; structures/institutions in society, in organisations or in the built environment that support such action and finally a vision that supports such action by individuals willing to grab the opportunities created by different technologies. The vision guiding the activity of changes should be rooted in the present world and in people's current set of values, as well as having validity for several different futures.

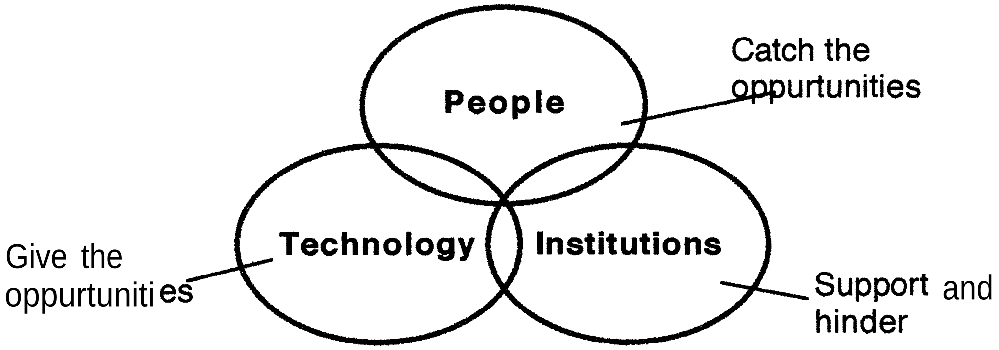

Figure 1. Co-operation between technology, people and institutions. [1]

What possibilities do we have for fulfilling the three pillars of change in the matter of sustainability? Do we have sustainable technology? Yes, *of* course! Are there people out there grabbing the opportunities which technology give us? *Some are and some are not!* Do the institutions support sustainability with regard to people's behaviour and technology? *Not enough!*

What conclusions can we draw from these answers? Firstly, that we don't need better sustainable technology. While the need for such technology remains large, what it needs is people who want to buy and use it. Secondly, some people are taking the opportunities and some are not. The immediate reason would seem to be that they don't believe in a society built on sustainability. That suggests a lack of vision or that they think it as too expensive without enough commensurate personal or economic gain.

2.1 People's values

People have different sets of values and therefore different ways of adopt new **technology and** of **making sacrifices for the benefit** of the natural environment. The **Kairo's Value Map,** KVM, **is a** multivariate analysis of **people's** values. It will cluster different values depending on their strength and on their relation to people's set of values.

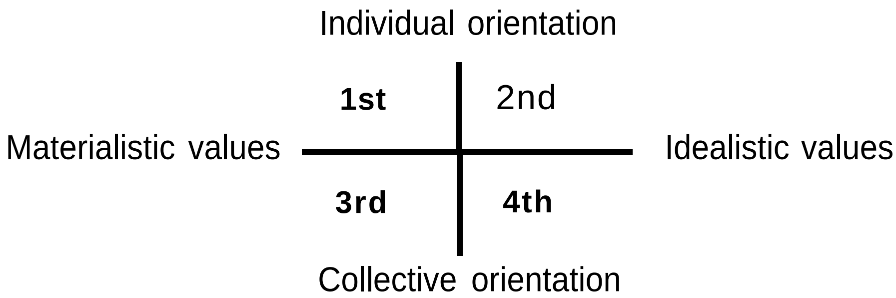

Figure 2
Kairo's Value Map, KVM [2]

If you apply the map to the population of Sweden (ages 16-65), most people willing to sacrifice for the benefit of natural environment will be found in the 4th quadrant and those most reluctant in the 3rd. You will find most people willing to try new technology in the 1st. In quadrants 1 and 2, you will find the most educated and affluent individuals. Of course these different value clusters need to be considered in designing new technology and in any vision for organisations seeking to attract customers and employees.

2.2 Institutions

Institutions and different structures in society, communities, organisations and the built environment either support or hinder deviating behaviour. The normality/abnormality of deviating behaviour depends on the values in the organisation. So called normal behaviour is both the outcome of people's values and of how different policies in company work as a system supporting and/or hindering certain behaviour. The built environment with it's infrastructure also influences people's actions by telling us what is regarded as normal.

I am convinced that your inner picture of the life in any city is supported by and reflective of the organisation and expressions that make up the built environment – that is your picture reflects your impressions of the city. The society, the community, the organisations and the built environment can be seen as systems supporting and/or hindering different behaviour. Sustainability may be fully supported by these system if such action is regarded as normal.

3 The art of making scenarios

Any vision must be valid for several different futures. One tool for exploring the future is making scenarios. These include three stages - collecting information, analysing the information and finally creating pictures of the future.

3.1 Collecting information

There are several ways of collecting information and it can be done at different levels. Depending on the time and effort spent on collecting information, a broad range of methods are available, including continuously reading and browsing media and having networks of scouts, experts, customers and other groups for future related discussions. You can also use one of several methods for interviews and public opinion surveys. Buying information and statistics from national or international data collections [3] is also a good alternative, especially if in doing so, you can track data, opinions and lifestyle changes over several decades.

In the main, information is found at three levels: 1. in the world around us, 2. in the industry and 3. in your own world. When collecting information from the surrounding world and in the industry, you should have a global perspective. When seeking changes, new inventions, shifts in opinions and the like over the last decades, you will end up with lots of information. One way to systemize this information is to divide it into different areas, like Technology, People and Institutions, to use a checklist like EPISTEL or perhaps choose some important areas from your own field. The letters in the acronym EPISTEL stand for the following subject areas: Ecological, Psychological, Institutional/Political, Social, Technological, Economical and Legal. EPISTEL is often used in analyse of effects of a larger project, such as for the bridge between Malmö and Copenhagen, but also to deal with all aspects of future study like the one on the future of Swedish newspapers - Morgondagens Dagstidning (The Tomorrow's Daily)[4].

3.2 Analysing the information

After collecting the information, the work of evaluating the information begins. By assimilating a lot of information, you often get a feel for where the future lies. That feel is always only one of several possibilities and often wrong. It is important to look at the different levels as separate systems, to do the analysis within the system and to generalise the information into events and trends of low and high effect for the system level in question. When making a scenario, you should exclude areas where your own action can alter the future, that is the your own world. While this level is clearly important, you can't do scenarios while including this level, as different scenarios would lead to different actions. You focus on trends and events of high effect for the surrounding world and your industry. On the global level, you can ask such questions as: What are the trends in IT, bio-engineering and new materials?

For a quick evaluation of the trends you will analyse two: 1. the probability of an event occurring and 2. the consequences if it occurs. Then you locate the trends in Figure 3 below.

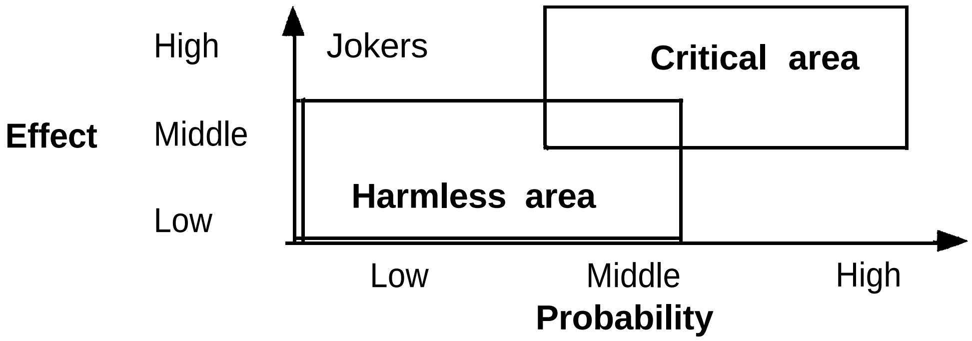

Figure 3. Effect and probability of trends. [5]

You should focus on events in the Critical area positioned in the upper right corner. Events in the upper left corner are jokers, ones with low probability but extensive consequences. These jokers should not be forgotten, even if they have low probability since their extensive consequences can make it necessary to include them in a scenario.

Next step is to evaluate each trend, asking such questions as: Where does the trend lie in a long or short term perspective? What is probability and effect of the trend? What is your knowledge about the trend, its size and reliability?

Once the evaluation is done, it is necessary to find relations between different trends and events. Some trends are only a consequences of other trends, Some trends are a driving force for other trends and some are driven by yet other trends. Some trends are neither drivers nor driven. Traditional cause and effect analysis building a tree of consequences would not be enough to describe systems of high complexity, like a society, company, organisation nor larger systems like nature and the built environment. To understand the connection between different subsystems and variables, you need other analysis methods. You can use a computer to do a multivariate analysis or use simpler methods like a cross impact-analysis, CIM [6]. With a cross impact-analysis, you can describe trends and variables in the figure below.

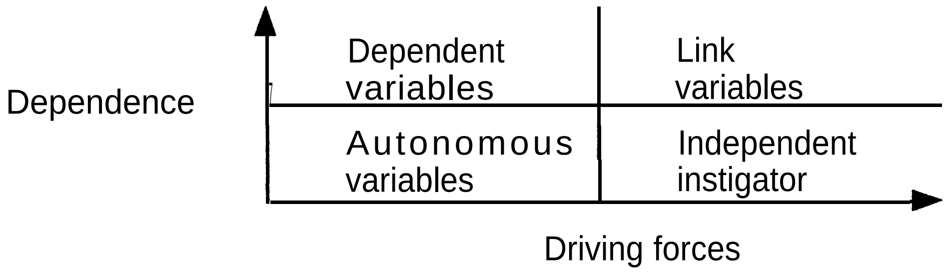

Figure 4. System of variables and trends [7]

Another, simple method is a four field-analysis [8]. You have to identify two of the most critical issues with extensive consequences. When working with scenarios for the built environment as whole, two issues which might show up at this point are: What are the trends for social and income related segregation? and What are the trends for the means of transportation? If we want to analyse these questions we can dichotomise them, describing the end points in clear contrast to each other. When we dichotomise these two questions we get four alternative scenarios:

A society with low segregation and small public transportation.
A society with high segregation and small public transportation
A society with low segregation and large public transportation
A society with high segregation and large public transportation

What can we learn more from this four field-analysis of each scenario? How probable are these scenarios? Which other trends can support such developments? What happens to other trends in the scenarios?

3.3 Creating a picture of the future
The two questions above are used to demonstrate how four field-analysis can teach us more about how different scenarios affect the built environment and sustainability. A number of other trends and issues are likely to lie on the same interest level. I have chosen 22 trends from the book Morgondagens Hem [9] (Tomorrow's Home) as examples of important trends, to whit:

New household structures: increasing number of separations, singles and smaller families.
The molecular family structure grows.
Increasing numbers of elderly.
Curing fur relatives is increasing.
Institutional child-cure a family affair?
Increased awareness of health.
Chasing new adventures.
A time fur small pleasures.
In harmony with nature.
The Real-time society.
Consumers are harder to please.
Rapid increase in the amount of information.
The pursuit of comprehensible environments.
Life-long learning.
A wurking life beyond time and space.
From steady to loose wurking cunditiuns.
Time versus money, a paradox.
The post-industrial dilemma,
New technologies enter the home.
Internet. Edutuinment - from watch to try.
On our way to equality between the sexes.

Trends supporting and driving other trends join to create a system, whose operation must be understood to be used to describe the most important scenarios vividly. What is the worst scenario and which is best scenario? What is the most probable scenario? What kind of pattern/metaphor shows the trends and scenarios? Is it ***Win or Loose,Challenge and response or Evolution versus organic growth.*** It is important to understand which pattern you are describing. For a long time, the connection between economy and environment was seen as a struggle, like in the metaphor ***Win or Loose.*** Thoughts like sustainability didn't fit the pattern, being a principle for both economic and environmental development.

4 The vision

4.1 Congruent values

4.11 Sustainability as a principle

For people to adopt a vision it needs to be congruent with their set of values. The vision must be described in the context of what is happening today. The raw material for building a vision about a future built environment is the current built environment and its inhabitants. If the built environment and people's values, or in other words their neighbourhood and their daily life, are very different as compared to other areas, share the vision with the other areas becomes problematical. You will have the same problem in sharing a vision not congruent to people's value sets in a company, organisation and society as a whole. If you regard sustainabilty as a principle, that is an accepted or professed rule of action or conduct, the key purpose of the vision is to motivate such action or conduct inherent in that principle.

The principle of sustainability is more important than sharing the same personal vision. We could share the same picture about what we don't want to happen, a global environmental collapse for instance, but my picture of my future is different from your picture of your future. What we can do is to establish areas of congruent visions in areas of congruent values.

4.12 Sustainability as a trend

A group of environmental activists have no problem understanding why they should set up a vision to support sustainability, but can companies making cars and houses have that same clear grasp of why they should share a vision supporting sustainability? Probably not for the same reasons as the environmental activists. While they would be more interested in a vision making better cars/houses and more profit, a sustainability vision is not incompatible. If you look at sustainability as a trend, that is on the trend's effects, probability and connections to other trends, you will find that it is a prime driving force with high effect on several system levels and with high occurrence probability. Ignoring such a trend will be critical at any system level when planning for the future.

4.2 The compelling vision

A vision's most important task is to be compelling, to describe a positive future. The motivation ta start the process of searching for and describing a vision can be a threat. A threat which also making you hold onto the old and secure and avoiding the forward-looking vision. The vision must be at least as attractive as the old and secure. Politicians who cannot describe their vision in terms more compelling than the old and secure must depend on old politics to be elected. Companies with the same problem are stuck with old customers.

Organisations with weakly attractive visions often have great problems. The members and employees remain tied to values, frames of reference and lifestyles which often are nut the same as those of their leaders. If you want to share the vision within the organisation, everybody must be involved in the process of creating that picture of the future. If you want to share the vision with the inhabitants, they too must be involved in the creative process.

4.3 The frames of the vision

In the process of making your picture of the future, your vision, you must remember that the vision is your tool for owning the future. Your vision is either impossible or within the framework of a possible future. Be careful not to describe a vision which requires too many changes in values in too short a period of time. Two other historic mistakes are: 1. to underestimate the changes caused by new inventions and 2. to underestimate the time these inventions need to get established on the market. When you enter today's reality you have certain momentum and direction. See Figure 5 below.

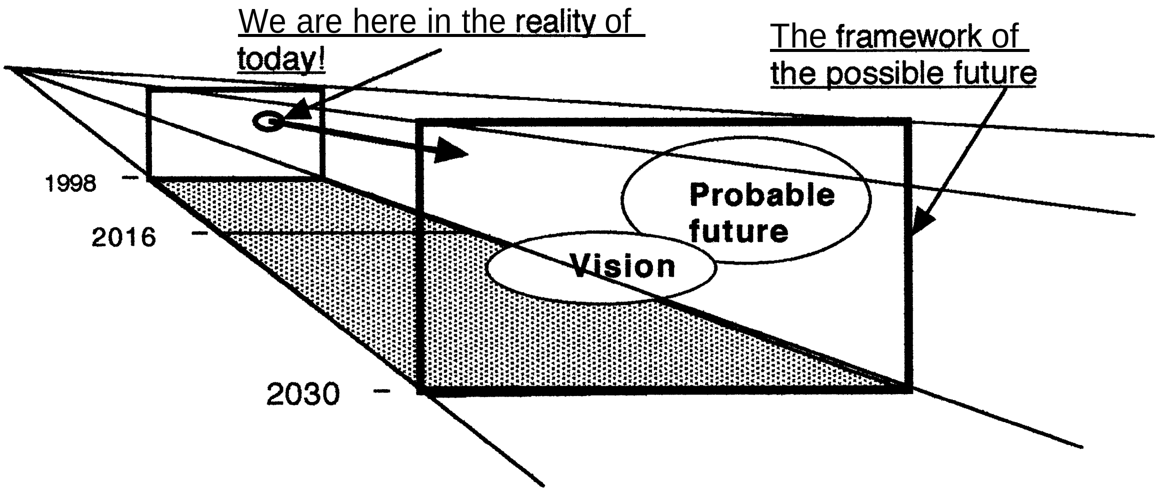

Figure 5. The connection between vision, probable future and the framework of the possible future.

The built environment will under all circumstances be here in 2030 and it will have a certain momentum and direction derived from today's reality. This momentum is the pace of change in the built environment and the direction is towards the probable future, If you want to have high probability of attaining your vision, it should be close to the probable future. If you want depart from the probable future, placing your vision as far away from it as possible, your probability of attaining your vision is much lower. Possible utopias lie close to the framework of the possible future and all mainstream planning lies within the probable future. Visions for supporting sustainability ought to lie somewhere in between mainstream and utopia. The vision should be valid for several different futures. Analyse the vision from the perspective of what the future world around us is like – 1. The Probable future scenario, 2. The best scenario, 3. The worst scenario, 4. Two unexpected scenarios. Evaluate and change your vision as needed in the light of the scenarios.

The vision should guide you into the future and inspire you to create your own future!

5 References

1. Molin, G. and Franzon, E. (1997) ***Morgondagens Hem.*** (Tomorrow's Home). Figure 1
2. Jegers, I. and Lindgren, M. (1992) *Morgondagens Värderingar* (Tomorrow's Values). Figure 2.
3. World Watch Institute publishes an annual describing several global issues in a long term perspective. This long term data can be ordered from the organisation.
4. Florén, P. (1997) *Morgondagens* ***Dagstidning*** (Tomorrow's Daily).
5. Lindgren, M. (1997) *Scenarioplanering* (Scenario Planning) Figure 3.
6. The CIM-analysis, ibid.
7. Figure 4, ibid.
8. The four field-analysis, ibid.
9. Molin, G. and Franzon, E.(1997) ***Morgondagens Hem*** (Tomorrow's Home).

Designing for Sustainability:
Ideal and Practical Increments of Change

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Abstract

The increase in discussion of life-cycle analysis and assessments has stimulated and reinforced the importance of being conscious of the future implications of design decisions. The majority of this discussion relates to the technical performance of buildings with little reference given to changing occupant needs and expectations. If technical advances in environmental performance are too extreme, or are in conflict with or compromise occupant expectations, they will ultimately prove ineffective.

This paper argues that if a primary value and role of innovative buildings is to inform and guide mainstream practice which follow in their wake, then the increment of the advances incorporated beyond mainstream practice, and their performance and acceptance through time, become critical design considerations. Case-study buildings are used to explore the way in which the performance of innovative environmental building can change through time through both deficiencies in technical performance and the actions of the building occupants as they attempt to adapt the building to suit changing needs or realign it with other time-honored expectations. To focus the discussion, environmental strategies which directly require the involvement of building occupants and which impact on their expectations are examined: moveable night-time insulation in passive solar buildings and the elimination of interior finishes.

The paper exposes practical realities which, if ignored, may ultimately temper the extent of significant environmental advancements in building design. Unless buildings can satisfy a range of use patterns, occupant expectations, provide comfort and ease of operation together with ongoing user education, and product replacement, it is unlikely that their intended performance will be sustained. This study is further evidence that innovative buildings require their designers to anticipate and account for a wider range of interpretations and performances - now and through time.

Keywords .
Innovative housing, Passive solar, Performance, User acceptance, Renovation

1. Introduction

The increase in discussion of life-cycle analysis and assessments has reinforced the importance of being conscious of the future implications of design decisions. However, Life-cycle analysis is primarily a quantitative analysis — dealing with the physical characteristics of building performance. Little, if any, reference is made to the changes in human expectations and occupant use patterns over the life of a building. Addressing the environmental agenda clearly requires significant improvements in building performance beyond current practice. But because we have yet to seriously challenge patterns of living, the primary architectural response to environmental issues has been one of providing increasingly better building envelopes and systems around fundamentally unchanged. occupant attitudes, expectations and actions. Therefore, if technical advances in environmental performance conflict with or compromise occupants expectations, they will invariably prove ineffective.

Case-studies on environmentally progressive buildings offer demonstration that environmental progress is possible, provide a measure of that progress and represent common ground for research and practice, designers and users. In fact they represent the *only* means by which we can fully understand the validity or acceptance of a particular environmental strategy. However, case studies are typically newly completed projects -the true merits or problems of which have yet to appear. Moreover, only the successes of case-study buildings are typically reported. Deficiencies, if any, are not publicly discussed, making it difficult to gain clear and complete understanding of progress.

This paper uses two case-study buildings to explore the way in which the relative performance of innovative environmental building can change through time -the *Kitsun* townhouse project, (1979) which has been monitored over a twenty year period, and a more recent project - the *Strawberry Vale Elementary School* (1996). In both cases alterations have been made to the original design, in part through deficiencies in technical performance, but more significantly through the actions of the building occupants as they attempt to adjust and adapt the building to both *time-honoured* and *changing* expectations regarding building performance and use. To further focus the discussion, the paper eaxmines two environmental strategies used in these projects which directly require the involvement of building occupants and which impact on their expectations: moveable night-time insulation and the elimination of interior finishes respectively. The paper argues that if a primary value and role of innovative building projects is to inform and guide mainstream practice which follow in their wake, then the *increment* of the advances incorporated beyond mainstream practice, and their performance and acceptance through time, become critical design considerations.

2. Moveable night-time insulation

A prominent strategy within solar housing during the 1970/80's was the use of moveable night-time insulation. As a strategy it represents the interface between user-involvement, comfort and energy performance. Experience with moveable night-time insulation at that time was showing'that moveable insulation, although an integral part of passive solar design, must be designed for fail-safe operation with careful. consideration to whether occupants are likely to use it correctly every day.

The *Kitsun* townhouse project in Vancouver, British Columbia is an eight-unit residential project. It was completed in 1978 and at the time represented the most advanced residential passive solar design in Canada. The key feature of the complex is the extensive array of south facing Trombe walls. This solar strategy was chosen primarily to provide visual and acoustic privacy given the minimal setback of the project from a major thoroughfare. The project also incorporated many state-of-the-art passive solar strategies when it was designed including Skylids on a 60° inclined 2.4 m wide by 1.2 m high skylight and insulating curtains on the 2.4 m wide by 4.8 m high poured concrete Trombe walls.

Initial monitoring of this highly publicized project concentrated primarily on its energy performance. Auxiliary energy use for space heat varied, due to differences in occupant lifestyle, from 1.5 GJ/year to 30 GJ/year for identical units [1]. However, for the design community, the remarkably low auxiliary energy use (averaging 8- 10 GJ/year) remained almost incidental to the building's aesthetic qualities. This. response resulted primarily from the stark visual contrast between the dark surfaces of the Trombe wall and the highly reflective quality of the insulating curtains, the visible deterioration and failure of the insulating curtains and the limited openings in the south wall being contrary to the large expanses of glazing typical of Vancouver housing

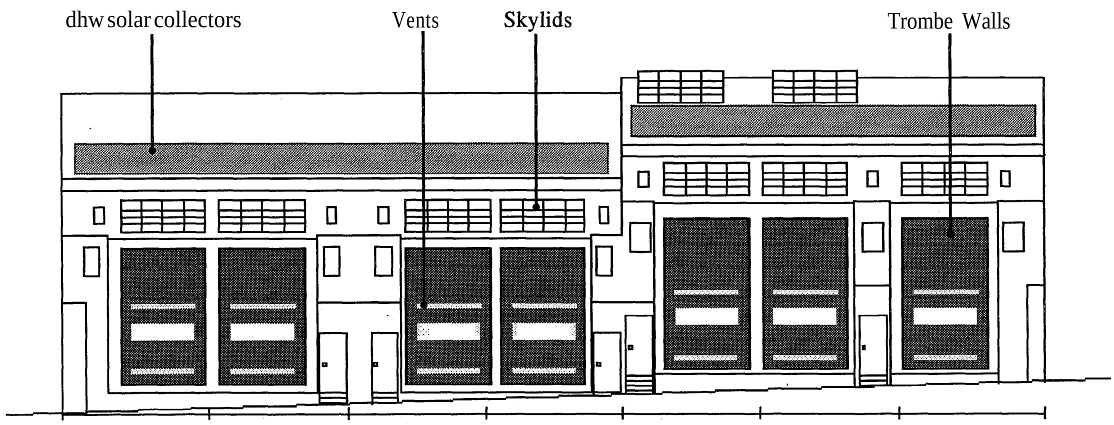


Figure *1:* South elevation of *Kitsun* townhouse project

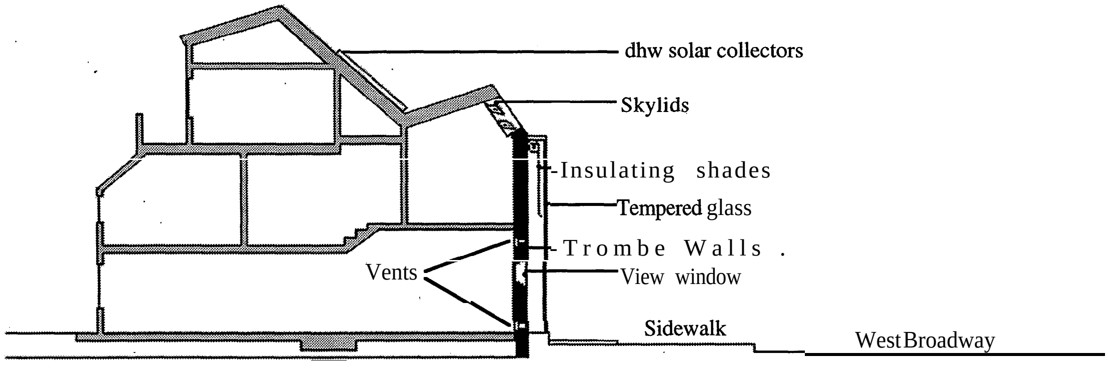


Figure 2: Section through a *Kitsun* 2-Bedroom unit (original insulating shades)

3. Mechanical failure of moveable insulation

The moveable Skylids and insulating curtains used in the *Kitsun* project served the dual role of night-time insulation and solar control against summer overheating and, as such, their effective use and performance assumes added importance.

3.1 Skylids

These initially generally functioned well after some adjustment, although they responded relatively slowly during periods of low insulation. The Skylids still generally operate and remain responsive to the day-night cycle as originally designed. However, because many of the occupants are 'unaware of their operating principle or unable to adjust and maintain them effectively, they either open and close abruptly, or very slowly They are, for the main part operated using manual over-ride.

3.2 Insulating Curtains on Trombe Wall

These had to be completely rebuilt in 1980 before they would operate under manual control with some care on the part of the building occupant. When operated automatically they would eventually crease and jam. Most occupants would operate the roll shade manually - opening it in the morning and closing it in the evening. Difficulties in providing effective edge sealing and continuity created severely compromised the overall insulating offered by the insulting curtains. Solar control, however, is only a function of covered area and less dependent solely on the loose edge condition.

In an attempt to alleviate the technical operating problems of the insulating blankets, the 2.4 m x 4.8 m high curtains were split horizontally in two of the seven units within the first year of operation (units 2 and 3). This significantly reduced the bulk created along the seams of the curtains as they were rolled up. This successful alteration would have been implemented in the remaining units, were it not for their faulty motors. Today, the only insulating blankets which remain are the two which were split in two. Due to the failure and removal of the full height insulating curtains, deciduous trees were planted in front of the Trombe walls in the late 1980s. This was primarily to soften the appearance of the complex and any potential solar shading was seen as fortuitous. These trees did not survive due to pollution and human abuse, but the strategy'has recently been repeated.

4. Human expectations/requirements

A decade ago, a glance at the south facade of the *Kitsun* project at any time-of the day or night during the summer and winter revealed varying degrees of use of the moveable systems. This was only in part due to their unsatisfactory mechanical functioning. The major differences originated from different comfort and environmental preferences of the respective occupants [2].

4.1 Limited daylight/view

An inevitable characteristic of townhouses is the potential daylight/view from only two sides. The limited south-facing window on the ground floor living/dining area in combination with an elongated floor plan compromises daylighting. Moreover; the insulating curtains further reduced daylight potential when they obscured the aperture within the Trombe wall. This conflict between two performance requirements (thermal and daylight) necessitated the positioning of the blind immediately above the aperture. In the two units retrofitted for split curtains, although the insulation properties are compromised, the residents are able to fine tune the extent and location of the curtains and can have daylight and some visual contact with the outside from the upper vent when the primary aperture is obscured.

4.2 Painting of the Trombe walls

Clearly technical and highly visible failure of the retractable insulating curtains have been a recurring problem and a key reasons for many of the subsequent changes. The outer surface of the Trombe walls were originally painted dark colour to increase the solar absorption. Each of the units were painted a different dark colour to provide a degree of individuality and variation while still maintaining a solar absorptivity greater than 0.85. These were subsequently all painted black to enhance the solar absorption In 1994 the occupants collectively agreed to have the Trombe wall repainted to lighter pastel colours. This modification has tempered the stark appearance of the project and reduced the solar loading on the mass wall during the summer, given the absence or ineffectiveness of the reflective curtains. Residents have noticed a perceptible reduction in overheating but no significant changes in their heating bills

	Insulating curtains		Trombe wall colour		
	By 1987:	**By 1997:**	**1979:**	**1987:**	**1997:**
Unit 1	Original curtains remain. Manual operation only. Rarely used during winter, closed during the summer to control excess solar gain.	Curtains removed	Black	Black,	Lt. violet
Unit 2	Original 4.8m curtains replaced with two 2.4m high segments, but otherwise generically similar. Used conscientiously for insulation and solar control.	The two curtains remain. Used judiciously for night-time insulation.	Dk. blue	Black	Lt. blue
Unit 3	As Unit 2 above.	The two curtains remain, upper not functioning. Used judiciously for insulation.	Dk. red	Black	Lt. green
Unit 4	Manual operation only. Used mainly in summer to control solar gain.	Curtains removed	Dk. blue	Black	Lt. yellow
Unit 5	Curtains broken and unused.	Curtains removed	Dk. brown	Black	Lt. yellow
Unit 6	Curtains removed.	Curtains removed	Dk. blue	Black	Lt. peach
Unit 7	Manual operation only. Rarely used during winter, closed during the summer to control excess solar gain.	Curtains removed	Black	Black	Lt. pink

Table 1: Changes made to Trombe Walls (units 1-7 from left to right in *Figure 1*)

4.3 Introduction of metal fence

Unlike other residential projects on this prominent street, the major south facade of the Kitsun project is almost at the sidewalk, bringing passers-by in close proximity to the 'front entrance' of the complex. Further, proximity to a local club creates additional noise and'periodic unsociable behaviour immediately outside. The introduction of a metal

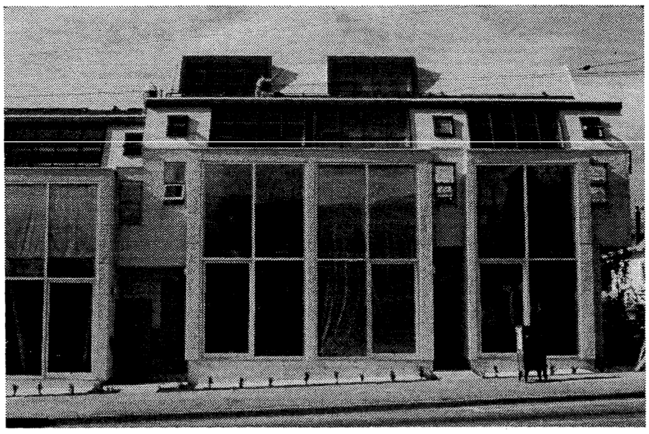


Figure 3a: ***Kitsun*** *Townhouse* project (Units 4-7) -1979

Figure 3b: ***Kitsun*** *Townhouse* project (Units 4-7) - 1987

Figure 3c: ***Kitsun*** *Townhouse* project (Units 4-7) -1997

fence in 1995 now defines a semiprivate realm for the complex and has created a new opportunity for landscaping and personalising the immediate foreground to the project through the planting of deciduous trees in a more protected environment adjacent to the solar wall and the introduction of heat resistant plants and other ornamentation behind the glazing.

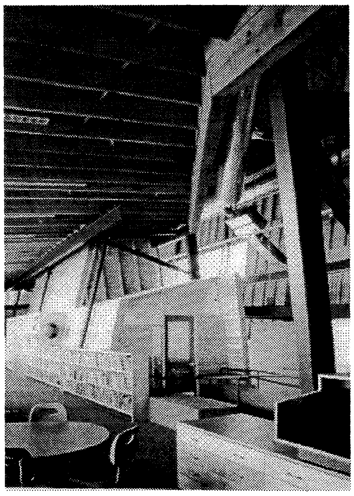
Re-examining a project like ***Kitsun*** some time after the initial period novelty and interest provides considerable insight into the longevity of passive solar strategies which rely on user acceptance and involvement. Many of the problems in this project result from the combination of the adoption of new design strategies and technologies, and the lack of foresight on. how the systems were likely to function through time and how they could be maintained effectively by their occupants. After ten years of occupancy, the performance and use of the ***Kitsun*** *Townhouse* confirmed the widely established experience of earlier passive solar houses that overly complex designs, from the standpoint of architectural and mechanical systems and the expected involvement by occupants in their operation, invariably fail. Moreover, not only should as much consideration be given to avoiding solar overheating as providing useful winter heating, but that the actual use and-interpretation of passive solar buildings will be different from the simplified energy and environmental schematics that are often used during their design After approximately two decades of occupancy, a potentially more significant change is evident. Significant modifications have been consciously made to the building's original design which are clearly contrary to its original solar emphasis, primarily as a result of changes in occupant understanding, expectation and desire to realign the appearance of the building with more conventional norms.

5. Eliminating finish materials

Many environmentally progressive buildings are attaining materials reduction through the deliberate *exclusion* of traditional interior finishing materials. This strategy represents one of the most visible and direct expressions of environmentally responsive design and one'which most directly impacts on the quality and character of interior spaces.

The *Strawberry Vale Elementary School,* Victoria BC, was completed in September 1996 [3]. All of the classrooms in this 3300 m^2 facility are oriented south toward a park and woods, and are located at grade for direct access to the outdoors. To limit the length of the school the classrooms are grouped in pods of four. .A meandering circulation spine connects the pods with the library, administration and gym.

In addition to a thoughtful consideration of a host of environmental characteristics of building materials, the amount of drywall was reduced by completely eliminated it in the main circulation spine and public areas *(Figure 4a)* and limiting its application to specific



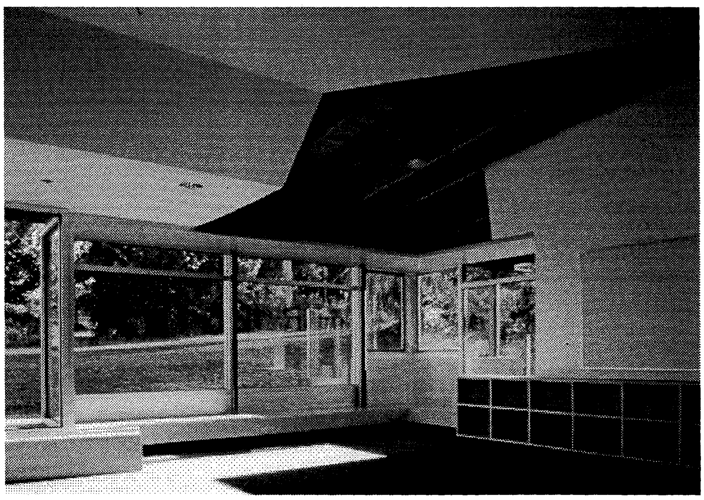


Figure 4a & b: Strawberry Vale School: Public Areas/Circulation spine and Classroom areas in the classroom spaces where it would be most effective at reflecting daylight (Figure *4b)*. This strategy was consistent with a broader architectural notion that the richness of a building derives, in part, through expressing how it was built. Similarly, finished concrete is used over extensive circulation areas and 'wet' areas to eliminate the need for additional flooring materials and attendant adhesives. Although the actual amounts of materials saved through these strategies in terms of mass or volume is modest, the visual impact is profound. It emphasises and communicates the need to be selective in the use of materials rather than unthinkingly applying anywhere and everywhere.

Although all of environmental strategies were agreed to by the client at the outset, within less than a year of opening, changes have begun to be made to the interior which again are contrary to the original design intention. The original open plan reception area has now been enclosed — and sections of the finished concrete seating along the central circulation spine have been fitted with wooden tops. Unlike the *Kitsun* project where the benefits to time have revealed the full extent of the change, it is difficult to anticipate the extent or type of modifications which may be made to the school and whether any of the exposed areas of structured will be covered for acoustic, maintenance or other reasons. Irrespectively, it points to the difference between environmental strategies which challenge and impose more directly on occupant expectation from those which remain innocuous.'

6. Conclusions

The environmental agenda will require a significant improvement in the performance of buildings beyond current practice. The acceptance of environmentally progressive buildings is premised only in part on the energy and environmental benefits they offer. This paper has focused on some of the practical realities which, if ignored, may ultimately limit the extent and rate of significant environmental advancements. Unless buildings can satisfy a range of use patterns, occupant expectations, provide comfort and ease of operation together with ongoing user education and product replacement, it is unlikely that their intended performance will be sustained. This study is further evidence that innovative buildings require their designers to anticipate and account for a wider range of interpretations and performances - now and through time. Until such time that a broad-based environmental ethic develops and when building occupants are willing to reassess priorities and expectations, and participate more actively in building operation, the increments of technical advance incorporated into buildings must be carefully evaluated and set with reference to time-honoured expectations and qualities.

7. References

1. Cooper, K., & R.J. Cole, (1982). Kitsun Vancouver Passive Solar Townhouse - Monitoring Results & Evaluation' *Proceedings of American Council for an Energy Efficient Economy Workshop - What Works'*, U. California at Santa Cruz, 225 - 241.

2. Cole, R.J., and Steiger, M., Leaps of Faith - Innovative Environmental Buildings,- *(1997). Proceedings SESCI Annual Conference: Implementing Sustainable Energy in a Changing World,* Vancouver, BC June 5-7th 1997, pp16-21

3. Macdonald, C., (1997). Education Buildings: Eloquent Resistance, *Canadian Architect,* May 1997, pp16-23

Sustainable Constructions* Strategies from the Technological / Biological Perspective

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Abstract

The demand for a massive volume of healthy homes in the last **20 years** in the world, also in Romania, together with the demand for the design and realization of healthy autonomous energy houses, appear now, towards the end of this millennium, under many contradictory sides:

- the affordable living through the **social cost** of the building integration into the urban space and in the constructions' strategies;

- the comfortable living through the imposed degrees of functional, aesthetical, high-technological qualities of the buildings;

- the healthy living through the **eco-system levels of integration,** in a healthy environment;

in an area wherein **the strategies** and **the decisions** at the institutional level are very often low or not compatible. The paper proposes an approach from the technological towards the biological perspective for the living space development seeing the constructional effort to urbanize the space not 80% dominated by the contemporary tendency to build technologically but considering the real output of the building and its long distance effect on the environment.

As conclusions we mention:

- as long as we build for **men,** the real output of the living space can not be considered just from a **technological perspective.**
- where it is possible would be extremely interesting and useful to determine the correlation existing between the accumulating degree of forces, tensions (not only the seismic ones), other effects caused by the biofactors (side B, fig. 2) and the responsive time of the society.
- the biological perspective to think the strategies for any existing or new sustainable l i v i n g space, is imperative and no longer avoidable, against the economical wall. Through the contemporary way to think and build, we may not be able to control some devastating answers like the waterfall accumulations responses, as we are today witnesses on many levels and many countries.
- the freedom to build and benefit from a sustainable living space can not be real without being conscious of the **negotiable** edge between the technological and the biological way to design and which **is the real price** of a house.

Keywords: affordable, comfortable, healthy living, future perspective

Introduction

A **healthy** house can be characterized by the promotion of occupant health, energy efficiency, resource efficiency, environmental responsibility and affordability. Its design should promote superior quality of indoor environment (air, water and lighting, as well as minimal exposure to background sound and radiation), namely comfort. To afford a comfortable living space, considering that the energy consumption is to be reduced for space heating or cooling, water heating and various appliances, is critical when it comes to adaptability to the changing needs or number of occupants. Or more, in an increased number of homes or cities! Efficient use and durability of building materials and management of construction waste is considered the keynote of the present way to design. When it comes to decide the strategies' vectors and shapes it goes all back to the **output** of the building, be it home or social administrative building.

The Building Output Concept

The ecological time we live in as a reply to the frequent environmental crises, brings up to the surface of a debate how much we could objectively ask quantitatively and qualitatively from a living space, not being redundant for the environment or for the cohabitants? The living into big urban crowd places can not be acceptable without to consider the maximum admissible and measurable redundancy! On the way how the future living would look like, there are many suggestions for new forms **of** habitat such **as** *homes in homes, terrace homes, suspended flats, total homes*. Still keeping in mind the healthy house, whatsoever the name of the new solution, the problem of any sustainable construction bring the question of the building output. For its expression, very few mention all the categories from A to E (fig.1) in an analytical relation as an usual tool to evaluate the living space's qualities. In the physical sciences somehow bound to *man (people)* activities, like building houses, urban development, population growth, etc. the observational data of the manipulated, moving environment are different up from a point than in the physical sciences let's say more inorganically bound to the environment, such as Mechanics, Astronomy, Geology, even Archeology. Therefore searching just by the technological usual means (see η_{Th}, η_{Tc}, η_{Ec}- fig. 1) to prove the efficiency of a new or existing building, wouldn't be enough.
The **output concept** comes almost from Mechanics where the loss coefficient η defined as a ratio Q_g / Q_a between the thermal, mechanical, chemical, etc. absorbed energy Q_a and the given energy Q_g, shoes the economical degree in which a machine works. Or extended to us *a system works*.
Having this side of thermodynamics, essential for biology, biosociology, bioengineering because any living body, any scale, acts as a system wherein happens permanent and complex changes of energy, we could make the appreciation of the living:
A - strictly physical, measurable, approximating the house with a thermal machine, running irreversible changes through the thermal, water, electricity, gas sources. So comes the known technical outputs, classically defined through reproducible measurements of energies flows, consumptions, fluxes, even punctual instantaneous values of temperatures, air velocities, etc. Nothing goes **technically beyond the technological limitations** of the conventional energetic analyses, even if in a complex system, as any house is appears a powerful qualitative unequivalence when in or out of the house (the strict mechanical

A. Functional output η_F

- ⇨ Continuous/ discont. functions of basic installations: water supply, gas, electr., thermal
- ⇨ Grey energy administration
- ⇨ Use of retrievable energies
- ⇨ Building location in space: - poluted or not
  - green area, etc.
- ⇨ Functionals' quality: compartments

B. Technical output η_{Th}

- ⇨ Structure's safety
- ⇨ Thermal protection
- ⇨ Acoustic protection
- ⇨ Put out fire protection
- ⇨ Anticorrosion protection

C. Technological output η_{Te}

- ⇨ Work's costs on the building site
- ⇨ Technological costs of the prefabs
- ⇨ Transport costs for the building materials

The Living Space

D. Giobal economical output η EC

- ⇨ Estimations' costs
- ⇨ Materials consumption's cost
- ⇨ Work consumptions' costs
- ⇨ Energy consumption cost
- ⇨ Curent repairs and maintainance costs

E. Average psycho-social output η_{Ps}

- ⇨ Continuous /discont. build. hygiene assurance
- ⇨ Continuous / discont. collecting residues
- ⇨ The green level of the assembly
- ⇨ Natural accesses:
  - day light
  - fresh air, not conditioned
  - gardens, parcs

Fig. 1 - The global output of the building related to the environment

machine) are activating people (individuals, groups, big crowds).
So follows as necessary an other level to appreciate the living:
B - biophysical, partly unquantified, but obvious manifested through what we expressed in the fig. 1 as Functional output η_F(A) and η_{Ps}(E) Average psycho-social output.
For η_F and η_{Ps} there are not yet, like in the case of costs or consumptions, mathematical criteria or straight definitions to obtain illustrative values for the biophysic level of evaluation. Strictly mathematic, each of the outputs in the fig.1, might be interpreted as having equal or proportional **weights** (i.e. 20% or else) within the global output, but the real weight of each output type must be correlated with the physical or biophysical level from which we see it.

Evaluation Questions

At the physical level, with approximations with practical sense, we could evaluate no more than η_{Th}, η_{Te}, η_{Ec} covering according to the previous experience in the field, almost 60 % from all the aspects connected with the losses or economies of the living space. Apparently the rest of percentages left for η_F, η_{Ps} are commonly considered improved or ignored in relation with the others. Just at the biophysical level, because of the different scale and means of evaluations for the tensions, forces and accumulation effects, η_F or η_{Ps} become significant comparing to η_{Th}, η_{Te}, η_{Ec} which are no more operative further of **this level.**
We could easily conclude that the weight of the unmeasurable factors (fig. 2) in the evolution of **a sustainable built environment** is quite significant and could dominate the global cost of the building, the global output of the built space and determine responsible decisions in a preventive system. Their significance is also important to be considered in the functioning of the individuals as social elements, of the groups as environmentally integrated bodies, depending on a specific area and a time scale.
Starting from these evaluation questions and fig.1 we made a connection scheme in fig.2 to emphasize as significant for the contemporary living:

- **the measurable criteria practically** involved to evaluate the optimal functional
- **the unmeasurable by practical means criteria**, involved to appreciate objectively the optimum in living

The significance of the whole range of effects of the side B in the fig.2 is not included in any form or type of technic-economical balance. We therefore named them unmeasurable categories of effects, felled through environmental functions become stressful factors as consequence for the dysfunctions in the living system.
They become a significant counterpart in a type of balance, approached as a category of evidences between:

- Practical evaluable effects through
  - consumptions electrically, thermally, hydro, chemically, mechanically, etc. measurable
  - reproducible physical evidences through limited physical means
- Indirectly measurable effects sometimes unevaluable, coming almost from:
  - stressful conditions of living
  - unsuitable hygienical living
  - underdesigned environment coming from poor economical conditions
  - unsustainable built environment from the over polluted living conditions or over usage of often forbidden radioactive building materials

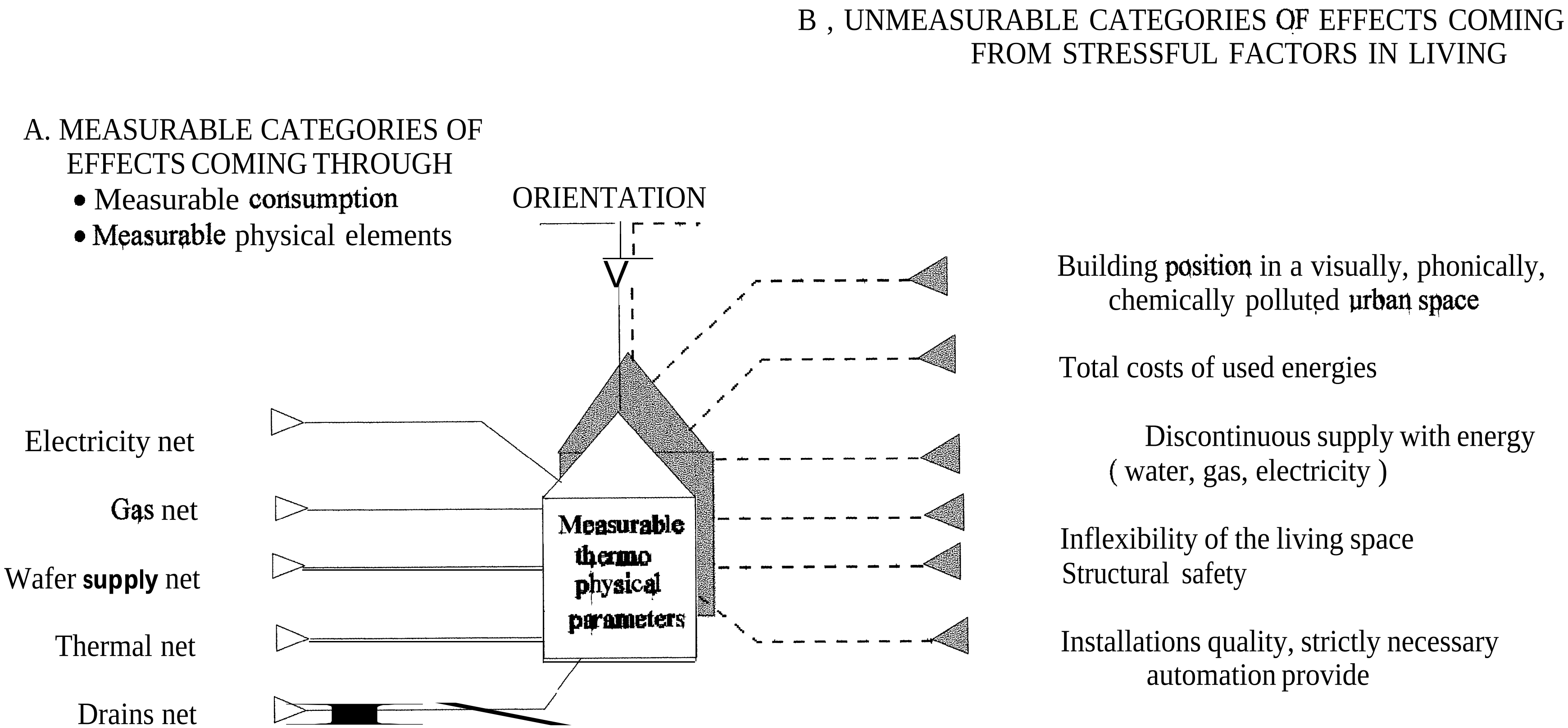

Fig. 2. New look over the measurable - unmeasurable balance
effects in the. living space

From the contemporary existent literature in the field, from some selectively chosen examples of the moments for some social disasters, appears like an evidence that we are far from understanding, analytically processing or using preventive tools of evaluation for the influences coming from the internal accumulations factors at the society level, due to its disfunction. There are unknown as in the case of the unmeasurable effects in the built environment, researches to emphasize some kind of such correlations.

Conclusions

•As long as we build for **men,** the real output of the living space can not be considered just from a **technological perspective.**

*Where it is possible, would be extremely interesting and useful to determine the correlation existing between the accumulating degree of forces, tensions (not only the seismic ones), other effects caused by the biofactors (side B, fig. 2) and the responsive temps of the society.

*The biological perspective to think the strategies for any existing or new sustainable living space, is imperative and no longer avoidable, against the economical wall.

*Through the contemporary way to think and build, we may not be able to control some devastating answers like the waterfall accumulations responses, as we are today witnesses on many levels and many countries.

•The freedom to build and benefit from a sustainable living space can not be real without being conscious of the **negotiable edge** between the technological and the biological way to design and which **is the real price** of a house.

References

1. Michrowski A., D. Arch. and J. Van Rhee, D. Eng. (1993) Brown's gas in autonomous energy homes. *Planetary Association for Clean Energy Newsletter,* Vol. 6(4), pp 10-2.
2. Margineanu D.G. (1985) *Biological Thermodynamics,* Univ. Bucharest.
3. Galambos R. (1976) *From Theoretical Physics to Biology,* North Holland Publishing Company, Amsterdam.
4. Dör F. (1983) Energetic and Statistical Relations, *Biophysics* Rev., W. Hoppe, Berlin
5. Todoran I. (1989) *Possible answers-Correlation and Prognosis,* Ed.Dacia, Cluj-Napoca.
6. Edsal J.T. and Gutfreund H. (1986) *Biotermudinamika,* Izdatelstvo, Moskva
7. Isac M. (1980) *Biophysics,* E.D.P. Bucharest
8. Placket R.L. and Burman J.P. (1943) Design of optimum multifactorial experiments. *Biometrica, No. 33,* pp 305-25.
9. Gunter B.H. (1993) How experimental design concepts can improve experimentation in the physical sciences. *Computer in physics,* Vol. 7, no. 3.

MODELLING SUSTAINABLE COMMUNITY DEVELOPMENT IN EDINBURGH'S SOUTH EAST WEDGE

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Abstract

Chester-ton's **(1996)** final report on the Edinburgh South East Wedge, represents the 'interim framework' for the development of a 1,400 hectare site on the edge of the City[1]. Commissioned by a consortium of public-private sector interests, including the former Regional and District Councils, enterprise agencies and respective landowners, the document provides the said 'partnership' with the strategic guidance and direction required to develop an area of land wedged between the City's South East boundary, green belt and surrounding settlements of East and Mid Lothian.

This paper aims to set out the new style of economic development and environmental planning the interim framework for the Edinburgh South East Wedge represents by looking at the conceptual model the proposal draws upon and by examining the principles of sustainable community development the plan puts in place to balance the conflicting demands of growth, expansion and conservation in the City. The paper suggests that the model of sustainable community development adopted for Edinburgh's South East Wedge is flawed in the sense it relies too much on the economic development of land and property markets and does not give sufficient attention to the ecology of environmental planning.

Keywords: economic development, environmental planning, sustainable communities.

New style planning

As an experiment in the new style of economic development and environmental planning, the framework's strategy for the 'balancing' of development, growth, expansion and conservation, proposes to adopt the principles of sustainability as a means of improving the relationship between the natural and built environment. In addressing this matter, the framework suggests the answer to this question of 'balance' and search for a form of development which reconciles the competing demands of growth, expansion and conservation, lies the distinctive urban design, layout and pattern of settlement the interim framework sets out for the growth and expansion of the City into the area of land known as Edinburgh's South East Wedge.

The conceptual model

The distinctive form of urban development it proposes is set out in the conceptual model of the South East Wedge. What the model proposes is that the design, layout and settlement pattern of the distinctive urban development in question should be based on:-

- the integration of existing urban settlements with new community developments;
- the planning of a new community development in a responsible, sustainable way;
- the development of a strong landscape framework.

Defining integration as the effective fusion of existing settlements with the new community forming part of the proposal, the report suggests the South East Wedge has the potential to create a distinctive urban character for the land in question via the formation of three distinct clusters of settlement. Three distinct settlement clusters, linked by the public transportation corridor, the framework also proposes, should be developed for such purposes. Expanding on this point, the document proposes the distinct urban character of the development should take the following form:

- the regeneration of a run down urban settlement;
- the expansion of an existing settlement;
- development of a new community.

In total, the framework anticipates that the clusters of settlements and new community will provide about 5,000 additional residential units and an expanded resident population of approximately 20,000. Reflecting further on the question of urban form, the document states: ".... the urban design challenge will be to create a high quality living and working environment. The [regenerated, expanded and new community] neighbourhoods should be conceived as essentially **urban** in character and designed on the following principles of sustainable development." (p.5). The principles in question are those of settlements and communities exhibiting:

- a spatially compact urban form;
- a high density of population;
- a balance of uses, economic and social structures;
- energy conscious public transportation;
- designs to provide a high quality living and working environment in identifiable neighbourhood units;
- a strong degree of financial viability in the short, medium and long term horizon.

The principles in question

The question of a spatially compact urban form can be read in a number of ways. First, as a development and environmental strategy on a sub-regional scale, the framework can be seen to concentrate the pressure for growth and expansion in one part of the city and conserve the environment of others. Secondly, on the district scale, it can be seen to concentrate pressure for growth and expansion in a collection of settlements, clustering them together in a form that avoids coalescence and conserves the environment (see figure 1).

It is this clustering of growth and expansion into existing settlements and new communities, while conserving the environment, that requires higher population densities. The balance of uses: residential, commercial, infrastructural and communal, are required for the communities to form four identifiable neighbourhood units. The question of energy conscious settlements rests with the high level public transportation network proposed for the development. This transportation network includes a number of measures such as a public transport corridor; bus priority proposals; park and ride provision and traffic calming. It also proposes that some of the neighbourhood units should be car free and residents ought to be within easy walking distance of public transport facilities. Together this combination of design factors are seen to provide for a high quality living and working environment, further augmented by the fact that the principles of sustainability underlying the development of the South East Wedge are to be strengthened by the layout and settlement of both communities and neighbourhood units in accordance with a 'strong landscape framework'.

The matter of financial viability tackles the particular difficulties the site confronts in terms of geo-technic problems associated with the extensive mining activities previously carried out in the area. Given the 'abnormal' site preparation costs, high infrastructure and communal content, the framework sets out what the strategy for the development, growth, expansion and conservation of the environment yield in the form of land receipts. As the viability study points out, the assumptions of the exercise and calculations show a net welfare improvement (in the form of an internal rate of return) of 8% p.a. over an inter-generational development period of 20 years.

Sustainable community development

It is evident that the distinct urban form proposed for the South East Wedge follows the commitment to sustainable development found in *The Bruntland Report* and in the EU's *Green Paper on the Urban Environment* [2-3]. The latter, having a

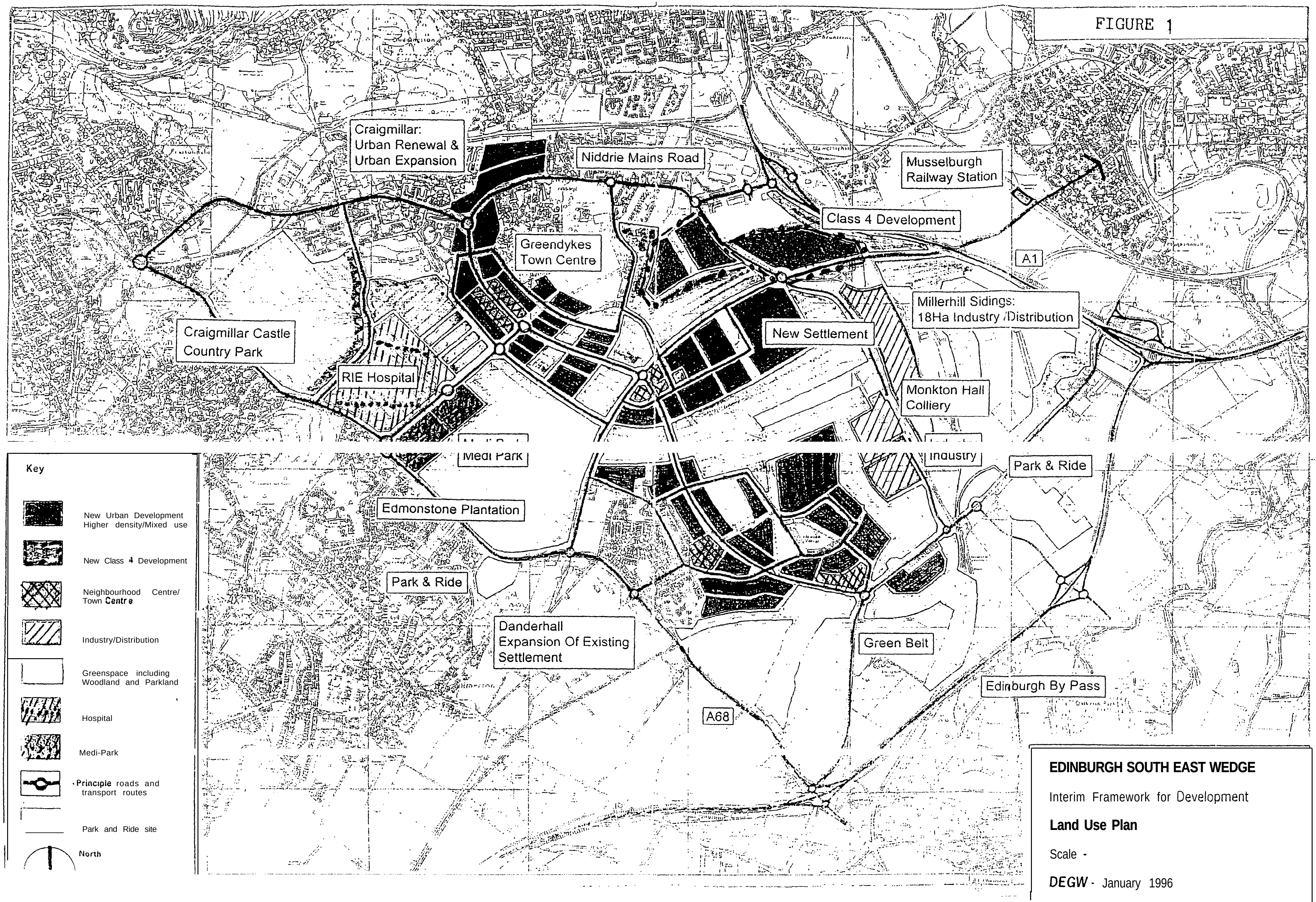

FIGURE 1
Craigmillar: Urban Renewal & Urban Expansion
Niddrie Mains Road
Musselburgh Railway Station
Class 4 Development
A1
Greendykes Town Centre
Millerhill Sidings: 18Ha Industry /Distribution
Craigmillar Castle Country Park
New Settlement
RIE Hospital
Monkton Hall Colliery
Medi Park
Industry
Park & Ride
Edmonstone Plantation
Park & Ride
Danderhall Expansion Of Existing Settlement
Green Belt
Edinburgh By Pass
A68
Key
New Urban Development Higher density/Mixed use
New Class 4 Development
Neighbourhood Centre/ Town Centre
Industry/Distribution
Greenspace including Woodland and Parkland
Hospital
Medi-Park
Principle roads and transport routes
Park and Ride site
North
EDINBURGH SOUTH EAST WEDGE
Interim Framework for Development
Land Use Plan
Scale -
DEGW - January 1996

particular commitment to the development of sustainable urban forms in terms of the compact city, with higher densities, balanced uses and energy conscious forms of public transport, reducing the need to travel and providing high quality living and working environments for communities with identifiable neighbourhood units. It is a form of commitment also reflected in the UK Government's *Common Inheritance,* the EU's *Towards Sustainability* and reiterated in the *Rio Earth Summit* [4-6]. Commitments to compactness, high densities, mixed uses and energy conscious public transportation most recently promoted in the UK Government's *Sustainable Development Strategy, Planning Policy, Guidance Notes,* (PPGN's) Nos. **12** and **13** [7-9]. Arguments on urban form, design, layout and settlement, also well rehearsed by Elkin, McLaren and Hillman (1991), Breheny (1992a; 1992b) Owen (1992), Nijkamp and Parrels (1994) Haughton and Hunter (1994) [10-15]. Arguments that Rydin (1997) points out, while well rehearsed are ultimately contestable, representing a discourse within the policy community and networks of the UK that is difficult to either draw upon or operationalise as a means to measure the exact degree of commitment which exists to the development of sustainable communities [16].

Sustainable community development in Edinburgh

While contestable, what is clear is that strong evidence does exist to show the policy community in Edinburgh draws heavily on *This Common Inheritance,* the *Sustainable Development Strategy* and *PPGN's* 13 *and* 14 and form networks of communication which operationalise such instruments by guiding and directing the growth, expansion and conservation in question through a consultative and partnership approach to urban design, layout and settlement [17]. It is perhaps, however, the matter of what form the planning guidance and direction takes within the policy community and networks of Edinburgh's South East Wedge that represents the question in hand and matter which requires particular attention. For while the interim framework is put forward to represent a radical experiment in the shift away from property market-led development and towards forms of environmental planning under the policy commitment to sustainability, it is evident a number of the conventions underlying the former type of development can still be found in environmentalism of the latter. This is because, far from representing a break with convention, it is evident that many of the neo-liberal traditions underlying the pro-growth, expansion-minded development rhetoric and enterprise culture of market economies, also survives the transition towards environmental planning - albeit under the more inclusive rubric of economic development, growth, expansion and environmental conservation [18].

The way in which the framework for the South East Wedge manages to stick with convention, rather than make a radical break with tradition is instructive and deserves further attention. This is because in focusing attention on the continuation of past trends, conventions and extension of traditions built up over the past decade, it has the effect of highlighting questions about the communicative and technical qualities of enterprise culture founded upon the civic virtues, consultation, partnership and competition of pro-growth, expansion-minded economic development, while drawing attention away from matters concerning the transition to appropriate forms of environmental planning strategy and conservation [19-20]. The tactic the framework adopts in this aim is simple. What is does is to focus attention on the one common denominator in the 'economic development cum environmental planning strategy' equation, that of the 'market' and questions about the use which land should be put in order for the economic development and environmental planning strategy to meet the needs of growth, expansion and conservation. What this does is reduce the question of economic development and environmental planning strategy surrounding the matter of distinctive urban forms, design, layout and settlement patterns to concerns about the use of land in sustainable communities. To be more precise, to the economic development and environmental planning of land as the strategic means to balance growth, expansion and conservation in the production of distinct urban forms, layouts and settlements for sustainable communities.

As a form of land management, the economic development and environmental planning strategy the framework adopts for this purpose also has to be recognised as having its rationale firmly rooted in the market. For nowhere in the framework do the proposals for the development of the South East Wedge manage to transcend the market or its mechanisms for the allocation of uses to land. This is because in line with the conventions and traditions built up over the past decade, the main point of concern lies not so much with the communicative and technical demands of an economic development cum environmental planning strategy, as with the accountability, value for money, economy, efficiency and effectiveness disclosures needed to fund expenditures on the servicing of infrastructures with abnormal costs under the growth, expansion and conservation measures laid down for the South East Wedge [21-25].

Of perhaps even greater concern is the fact that in restricting the economic development and environmental strategy to the market, the framework also reduces the form of environmental economics it takes to a question over the exchange of land and as a consequence is silent on the question of built forms. This has the unfortunate effect of concentrating attention on the release of development value from the economics of the environmental planning strategy and 'gain' resulting from the allocation of land into a distinct urban form, layout and settlement pattern, rather than the impact resulting from the engineering and construction of the buildings forming the sustainable communities in question, Nowhere does the examination transcend the market for land, or matter of planning gain. Neither does it manage to address questions about built forms, attempt to 'green' economic development, or make planning 'environmentally friendly' by either 'valuing the environment', or 'costing the earth' through impact assessments based on a full cost pricing mechanism, hedonic, or contingency style appraisal [26-27].

Some comments on the South East Wedge

If it can be accepted that the interim framework takes a sectoral rather than holistic approach to the development of the South East Wedge - if only for the fact its urban character centres on land uses as opposed to the built, let alone natural environment - it is necessary to identify the reasons for this so a more meaningful search for sustainable communities can be undertaken. The following discussion will do this by making a number of comments on the development of the South East Wedge:

- first of all, it has to be recognised the problems do not lie in the confusion over the meaning of sustainability in terms of either its economic or environmental components [28-29] but in how it is drawn upon and operated as a tool of economic development, growth, expansion and environmental conservation. The problem lies in the fact it reduces the issue to a question of land management under market exchange, rather than appropriate form of economic development and environmental planning strategy for land and buildings.
- the effect of this is to leave the economic and environmental relationship between the distinct urban form, clustering, identifiable communities, neighbourhood units and coalescence restrictions of the framework unclear. The economic and environmental nature of the relationship between spatially compact urban forms, separate communities and neighbourhoods needs further clarification. At present it cuts across what are accepted to represent alternative models of highly concentrated compact, or decentred and dispersed forms of communities [32-33]. As it is, the image of such urban forms goes back to the early modern reformers such as Howard, Geddes and Abercrombie, how compatible these are with the economic development and environmental planning of the contemporary era is not evident and needs to be clarified if further confusion is to be avoided.
- if the exact nature of the said relationships are to be clarified, it is evident that it will be necessary to get behind the 'green gloss' of the 'economically efficient' and 'environmentally friendly' development images of the framework and inject a much stronger ecological dimension into the analysis. Like, for example, that which exists in the debate on 'carrying capacity' [33-34]. At present and contrary to what is proposed, it is the economics of land and property market development, rather than the ecology of environmental planning that lies at the centre of the framework. What the framework needs to recognise is that the two exist independent of each other and the question is whether the latter has the capacity to carry the former and not the other way around! Asking this question opens up a much neglected issue of the framework - that of environmental impact assessment as a development planning tool, be it to do with the effects of the urban form, density, use, transport or any other such matter.
- at present the framework is not only too far removed from the ecology of environmental planning for any credible form of impact assessment, but equally too isolated from the urban and regional structure of the city the communities and neighbourhood units in question form part of. This is particularly noticeable in the matter of transportation, for while the framework raises a number of questions about impact of transport on the South East Wedge and City as a whole, it focuses on the former and excludes the latter. At present there is little evidence available to suggest that a City-wide assessment of the impact which the development of the required transportation networks will have upon Edinburgh exists, for while the plan says it 'hopes' the impact will stay within projected levels, it also goes on to say may not.

- it is also clear that the discounting mechanism the framework draws upon for the appraisal of development land is too simplistic in the manner it echoes the logic of Alonso (1967) and Denman (1972) [35-36]. In its current form it fails to give due recognition to the uncertainty and risk which underlies the development, is deterministic as opposed to probabilistic and as a consequence is not duly sensitive to the contingencies it faces [37-38]. The fact it also reduces the appraisal to a measurement of receipts from land sales means that it only captures about 20-30% of the capital expenditure in question and little, if any of the subsequent revenue commitments. Perhaps of greater significance though is the fact that such an appraisal restricts the measurement of income to capital receipts from land sales, relative to expenditure on the servicing sites, rather than capital costs and revenues from the engineering and construction of built structures forming the bulk of the development. In effectively negating the possibility of adopting 'net annual return' models for the development of land and buildings, it undermines the ability to not only measure the rate of return on capital investment from the economic development in question, but makes it virtually impossible to measure the ecology of the environment it also plans to produce in any meaningful way [39-40].

Summary

From this brief examination of the framework for the South East Wedge of Edinburgh, it is evident that as an experiment in the new post-l 990 style of plan-led economic development and environmental planning strategy, much of the growth, expansion and conservation, still leaves the balancing of the relationship between the natural and built environment to the market. If heavy reliance on the plan as an instrument of strategic guidance and direction means that a great deal of the urban form, design, layout and settlement proposed in the name of sustainable development is left to the economics of the land and property market and fails to penetrate the ecology of the environment, it has to be recognised the consensus surrounding the framework's claim to create sustainable communities with neighbourhood units, will begin to come under pressure.

References

1. Chester-tons. (1996) *Edinburgh South-East Wedge,* Final IDF Document.
2. WCED. (World Commission for Environment and Development). (1987) Our Common *Future,* Oxford University Press, Oxford.
3. CEC. (Commission of the European Communities). (1990) Green *Paper on the Urban Environment* (EUR 12902 EN), Commission of the European Communities, Brussels
4. DOE. (1990) *This Common Inheritance : Britain's Environmental Strategy* (Cmnd. 1200), HMSO, London
5. CEC. (1990) *Towards Sustainability : A New European Programme of Police and Action in Relation to the Environmental and Sustainable Development,* Corn. (192)23, Final, CEC, Brussels

6. United Nations (1992) *Agenda 21: The UN Agenda for Action from Rio,* United Nations, New York
7. DOE. (1994) *Sustainable Development : The UK Strategy, HMSO,* London
8. DOE. (1992) *Development Plans and Regional Planning Guidance, HMSO,* London
9. DOE and Department of Transport. (1994) *Planning Policy Guidance : Transport* (PPGN, 13), HMSO, London
10. Elkin, T., McLaren, D. and Hillman, M. (199 1) *Reviving the City : Towards Sustainable Urban Development,* Friends of the Earth / Policy Studies Institute, London
11. Brehney, M. (1992a) The Compact City, *Built Environment,* Vol. 18, No.4
12. Brehney, M. (1992b) *Sustainable Development and Urban Forms,* Pion, London
13. Owens, S. and Cope, D. (1992) *Land Use Planning Policy, HMSO,* London
14. Nijkamp, P. and Parrells, A. (1994) *Sustainable Cities in Europe : A Comparative Analysis of Urban Energy Environmental Policies,* Earthscan Publications, London
15. Haughton, G. and Hunter, *C.* (1994) *Sustainable Cities,* Jessica Kingsley, London
16. Myerson, G and Rydin, Y (1996) *The Language of Environment: A New Rhetoric,* UCL Press, London
17. Rydin, Y. (1997) Policy networks, local discourses and implementation of sustainable development, in Baker, S., Kousis, M., Richardson, D. And Young, *S., The Policies of Sustainable Development,* Routledge, London
18. McGuigan, J. (1995) *Culture and the Public Sector,* Routledge, London
19. Healey, P. and Shaw, T. (1994) Changing meanings of the environment by planners in the British planning systems, *Transactions of the Institute of British Geographers,* Vol. 19, No. 4, pp.425-438
20. Blowers, A. (1993) *Planning for a Sustainable Environment,* Earthscan, London
21. Evans, R. (1997) From town planning to environmental planning in Blowers, A. and Evans, B. *Town Planning into the 21st Century,* Routledge, London
22. Imrie, R. and Thomas, H. (1995) Changes in local governance and their implications for urban policy evaluation, in Hambleton, R. and Thomas. H. *Urban Policy Evaluation*, Paul Chapman Publishing, London
23. Martin, S. and Pearce, G. (1995) The evaluation of urban policy project appraisal, in Hambleton, R. And Thomas, H. *Urban Policy Evaluation,* Paul Chapman Publishing, London
24. Deakin, M. (1997a) Computer-based information systems for local authority property management : the underlying issues, *Journal of Financial Management of Property and Construction,* Vo1.2, No. 1, pp.59-83
25. Deakin, M. (1997b) Computer-based information systems for local authority property management : The application, *Journal of Financial Management of Property and Construction,* Vol. 2, No.2, pp.59-85
26. Pearce, D. and Turner, K. (1990) *Economics of Natural Resources and the Environment,* Harvester and Wheatsheaf, Hemel Hempstead

27. Turner, K., Pearce, D. and Bateman, I. (1994) *Environmental Economics,* Harvester Wheatsheaf, London.
28. Pezzy, J. (1989) Definitions of sustainability, *UK CEED Discussion Paper No.* 9, London
29. Redcliff, M. (1997) Postscript: sustainable development in the twenty-first century, in Baker, S., Kousis, M., Richardson, D. and Young, *S. The Politics of Sustainable Development,* Routledge, London
30. Elkin, T., McLaren, D. and Hillman, M., (1991) op.cit no. 10
31. Brehney, M. (1992b) op.cit no. 12
32. Haughton, G. and Hunter, C. (1994) op.cit no. 15
33. Pearce, D and Turner K (1990) op cit no.26
34. May, A, Mitchell, and Kupiszewska (1997) The development of the Leeds Quantifiable City model, in Brandon, P, Lombardi, P and Bentivegna *Evaluation of the Built Environment for Sustainability*, Chapman and Hall, London
35. Alonso, W (1967) A reformation of location theory and its classical relation to rent, *Papers of the Regional Science Association,* Vol. 19, pp.23-44
36. Denman, D (1972) *Land* Use, John Wiley, London
37. Balchin, P., Bull, *G.* Kieve, J. (1995) *Urban Land Economics,* Macmillan, London
38. Harvey, J. (1996) *Urban Land Economics,* Macmillan, London
39. Deakin, M. (1996) Discounting, obsolescence, depreciation and their effects on the environment of cities, *Journal of Financial Management of Property and Construction*, Vol 1, No.2, pp.39-57
40. Deakin, M. (1997c) An economic evaluation and appraisal of the effects land use, building obsolescence and depreciation have on the environment of cities, in Brandon, P., Lombardi, P. And Bentivegna, V. (1997) *Evaluation of the Built Environmentfor Sustainability*, Chapman and Hall, London

Validation of multilateral building product design by the QFD method

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Abstract
Building industries have developed highly specific materials and components to fulfil1 the CO2 requirements. A lot of work has been done on the optimization of building components with regard to the reduction of the energy loss by heat transmission. But in many cases this did not mean an integrated overall improvement in many properties for example such as insulation against sound and damp or the mechanical solidity and stability as required by the Building Products Act. The need for an integrated development of products in the construction sector can be deduced from this. Such an opportunity for integrated product development, taking account of all aspects right down to marketing, is provided by the method known as Quality Function Deployment (QFD). QFD is a quality-oriented, continuous planning method for products which take customers' wishes into account, specifying product development right down to individual details and influencing the implementation of the processes and the materials necessary for production. The procedure consists of a series of planning steps each of which is based on the previous one and which can be subdivided into four development phases. This QFD method and an evaluation is presented using the example of a novel roof structure. The procedure in planning the attachment of an insulation element to a substructure of cellular concrete is illustrated. In addition, both the possibilities and advantages offered by QFD are explained and the problems which may arise from non-methodical product development are shown.

Keywords: Building components, product development, planning method, Quality Function Deployment, description, evaluation

l Objective

To reduce CO, emissions from building heating, the new version of the Thermal Insulation Regulations came into force on 1 January 1995. An increasing amount of work has thus been done over the past few years on the optimization of building components with the regard to the reduction of transmitted heat loss. In many cases this did not mean an integrated overall improvement in properties, as the implementation of measures to increase thermal insulation, for instance, often lead to the neglect of other building-component properties such as insulation against sound and damp, not to mention the mechanical solidity and stability as required by the Building Products Act' [1]. In addition, an investigation carried out by the Fraunhofer Institute for Building Physics in collaboration with the Fraunhofer Institute for Production Technology and Automation [2] on the problems involved in the introduction of new and innovative building products from the point of view of small to medium-sized companies showed that difficulties regarding production technology or implementation which should really have been taken into account at the planning stage only become evident when the products are introduced onto the market. The need for an integrated development of products in the construction sector can be deducted from this. Such an opportunity for integrated product development, taking account of all aspects right down to marketing, is provided by the method known as Quality Function Deployment (QFD).

2 Approaching the solution with QFD

The QFD method originates from the mechanical engineering sector, where it has been successfully employed since the 1997s. QFD is a quality-oriented, continuous planning method for products which take customers' wishes into account, specifying product development right down to individual details and influencing the implementation of the processes and the materials necessary for production. ,The aim is to develop products with precisely the quality approximating most closely the customer's expectations and needs. On the other hand, collaboration and communication of all those involved in the development and production process means that development can be carried out very efficiently and attributably. The QFD procedure is described in detail in [2],[3] and consists of a series of planning steps each of which is based on the previous one and which can be subdivided into four development phases. Fig. 1 shows the method's sequence plan. At each of the individual steps the aim (What?) and the appropriate implementation (How?) are in each case interrelated to each other, the implementation (How?) automatically becoming the aim (What?) of the following step.

QFD thus enables customers' wishes for instance, to be sounded out already at the planning phase of future building-component developments and then translated into concrete technical requirements which then influence the entire product development. The QFD method has been applied by the IBP to building-specific requirements and actually applied in several cases (including [4]) in order to create one possibility for successfully implementing development tasks for building products.

3 QFD as exemplified by the attachment of roof insulation

The QFD method is to be presented as exemplified in a novel roof structure, and the procedure in planning the attachment of an insulation element to a substructure of cellular concrete illustrated in an abbreviated but nevertheless clearly understandable fashion. In addition, both the possibilities and advantages offered by QFD are to be explained and the problem which may arise from non-methodical product development are to be shown.

In the example mentioned, the following sometimes contradictory customer's wishes or requirements were taken into account:

- Thermal insulation (e.g. thermal resistance)
- Recyclability (e.g. separability of the insulation elements from the concrete)
- Erection costs (e.g. time needed for fitting) and
- Costs of materials

Tables 1 to 3 show, in a rudimentary way, the QFD procedure in the example in the example mentioned, and will be explained more closely during the talk: at the outset it is necessary to collate the customer's various wishes and to weight them (cf. Table 1). Table 2 shows the most important building-physics requirements for roof structures, such as thermal insulation in winter and summer, climate-related moisture insulation etc.. These are related to the customer's wishes in order to support, in the form of the resulting catalogue of requirements, the selection of various alternative construction possibilities, as shown in Table 3. A concluding evaluation in Fig. 2 is intended to present the influence of various weightings.

If a methodical product development is dispensed with, or if an error is made regarding the evaluation of the connections or the weighting at the start of the implementation of the QFD method, or if the customer's wishes are incorrectly recorded, this may lead to an erroneous decision and a faulty product which does not correspond to the requirements. This is demonstrated by the definition of two different weightings, namely:

- without erection costs
- with erection costs (high weighting)

The result is two completely different construction variants. From this fact, and from the example of successful implementation, verification of the method can be deduced.

4 Evaluation of the QFD method

An evaluation of the QFD method in the above-mentioned example shows several advantages and disadvantages. Basically, QFD is a procedure for technical experts, i.e. the method only leads to the desired success if applied in wellfounded cooperation with the customer with regard to weighting, connections and specification. The formulation of the mutual connections between the requirements and the construction variants should thus only be carried out by experts.

5 Bibliography

[1] Law Regarding the Marketing and Unrestricted Trading of Buiilding Products to Implement Guideline 89/106/EWG of the Council Held on 21 December 1988 to Align the Legal and Administrative Regulations of the Member States Regarding Building Products; Federal Gazette No. 39, 14 August 1992.

[2] König, N.; Sedlbauer, K.; Hartfuß, C.; Cottone, N.; Kamer, K.: The Building Site of the Future - Innovations for Civil Engineering. Concluding report of Research Project No. 620 190 of the Fraunhofer Institutes for Building Physics and for Production Technology and Automation, Stuttgart, 1996.

[3] Akao, Y.: Quality Function Deployment - How the Japanese Turn Customer' Wishes into Quality. Verlag moderne Industrie, 1995.

[4] Oswald, D.; Sedlbauer, K.; Wichtler, A.: Simple Roof Structures with Concrete Substructures. Report GB 138/97 of the Fraunhofer Institut for Building Physics.

Table 1: Registration and weighting of customers' wishes within the QFD method

CIB lecture Cellular concrete roof		QFD Phase 1 Situation: 10.12.97	Customer survey												Evaluation			
Customers' wishes and requirements with statement of weightning			1	12	13	14	5	16	17	8	19	10	11	112	Without target-group significance		With target-group significance	
			Initiator 1	Initiator 2	Initiator 3	Initiator 4	Contractor 1	Contractor 2	Architect 1	Architect 2	Architect 3							
			2	1	2	1	1	2	3	3	1	1	1	1		%		
1. **General**	1.1	Short construction time	9	3			9		3	1	1				26	**7,26**	43	**6,50**
	1.2	Independent of weather conditions	9	3			9		9	1	1				32	**8,94**	61	**9,21**
	1.3																	
2. **costs**	2.1	Construction at favourable cost	9	3			9		3	9	9				42	**11,73**	75	**11,33**
	2.2	Low operating costs	3	9			1		9	9	9				40	**11,17**	79	**11,93**
	2.3	Low maintenance costs	3	9			3		9	9	9				42	**11,73**	81	**12,24**
	2.4																	
3. **Building physics**	3.1	Good thermal insulation	3	3			1		3	9	3				22	**6,15**	49	**7,40**
	3.2	Good sound insulation	1	1			1		3	9	3				18	**5,03**	43	**6,50**
	3.3	Good moisture insulation	3	3			1		9	9	9				34	**9,50**	73	**11,03**
	3.4																	
4. **Living quality**	4.1	Variable interior surface	3	9			1		1	3	1				18	**5,03**	29	**4,38**
	4.2	High degree of cosiness	3	9			1		3	3	3				22	**6,15**	37	**5,59**
	4.3																	
	4.4																	
5. **Environment**	5.1	Environmentally-compatible product	1	9			3		3	1	3				20	**5,59**	29	**4,38**
	5.2	No danger of health	9	9			9		3	3	9				42	**11,73**	63	**9,52**
	5.3																	

Table 2: Interconnection of customers' wishes and requirements in accordance with Phase 1 within the QFD method

CIB lecture Cellular concrete roof		QFD Phase 1 Situation: 10.12.97	Requirements																																
			General					Costs							Building physics									Living quality				Environment				Wighting			
		Customers' wishes and requirements	1.1 High degree of prefabrication	1.2 Simple handling	1.3 On-the-spot fitting by crane	1.4 Independant of weather conditions	1.5 Simple disassembly	2.1 Low material costs	2.2 Low manufacturing costs	2.3 Low transport costs	2.4 Low fitting costs	2.5 Low maintenance costs (long life, low maintenance expense)	2.6 Low heating costs	2.7	3.1 Thermal insulation in winter	3.2 Thermal insulation in summer	3.3 Joint tightness	3.4 Protection against driving rain	3.5 Diffusion	3.6 Convection	3.7 Sound-proofing R'w,res > 43 dB	3.8 Low longitudinal sound conduction		4.1 Variable interior surface	4.2 Variable conversion of loft space	4.3 High degree of cosiness		5.1 No hazardous materials	5.2 Recyclability	5.3 No health risks	5.4 Positive eco-balance	Without target-group significance		With target-group significance	
1. General	1.1	Short construction time	9	3	3	9			3																							26	7,26	43	6,50
	1.2	Independent of weather conditions	3	3		9					1																					32	8,94	61	9,21
	1.3																																		
2. Costs	2.1	Construction at favourable cost	9	9		1		9	9	9	9																					42	11,73	75	11,33
	2.2	Low operating costs										9	9		3		1								1							40	11,17	79	11,93
	2.3	Low maintenance costs	1	1			3	1			1	9					1	3														42	11,73	81	12,24
	2.4																																		
3. Building physics	3.1	Good thermal insulation										3	9		9	9	1		3							9						22	6,15	49	7,40
	3.2	Good sound insulation																			9	9				9						18	5,03	43	6,50
	3.3	Good moisture insulation										9	3		3		9	9	9	3						9						34	9,50	73	11,03
	3.4																																		
4. Living quality	4.1	Variable interior surface																						9	3							18	5,03	29	4,38
	4.2	High gegree of cosiness													3	9	9				3	3		1	1	9		3				22	6,15	37	5,59
	4.3																																		
	4.4																																		
5. Environment	5.1	Environmentally-compatible product																										9	9	1	9	20	5,59	29	4,38
	5.2	No danger of health																										9		9		42	11,73	63	9,52
	5.3																																		
Sigmificance for solution variants without target-group evaluation			750	594	78	564	126	420	456	378	452	1110	660		486	396	608	432	372	102	228	228		184	116	864		624	180	398	180		100		100
Sigmificance for solution variants with target-group evaluation			1326	1068	129	1011	243	756	804	675	817	2244	1371		1008	774	1199	900	804	219	498	498		298	203	1818		939	261	596	261				

Table 3: Interconnection of requirements and solution approaches in accordance with Phase 2 within the QFD method

CIB lecture Cellular concrete roof	QFD Phase 2 Sitation: 10.12.97	Solution variants, paths to the solution, partial solutions: a) Mineral-wool insulation element					b) Rigid-foam insulation element					c) Joint formation in cellular concrete		d) Cellular concrete roofing tile				e) Tile fastening			Technical importance as per requirements			
	Requirements from Phase 1	S malbrmat	large fomat	G ¦:' on	Srew edon	naied ∞	S all fo rmat	large for mat	Glued on	Screwed on	nailed on	Torgue- and-groove	Insulation tape + tongue-and-groove	Sm^ format	large format	Laid parallel to gable-end	Laid parallel to ridge	Wooden laths	Steel without counter-laths	Tile holders moulded on	Without target-group significance		With target-group significance	
1.1	High degree of prefabrication		9					9							3						750	6,83	1326	6,40
1.2	Simple handling	9			3	3	9			3	3	3			3						594	5,41	1068	5,15
1.3	On-the-spot fitting by crane	1	1				1	1						9	3						78	0,71	129	0,62
1.4	Jndependant of weather conditions				3	3				3	3										564	5.13	1011	4,88
1.5	Simpledisassembly	3			9		3			9				9	3						126	1,15	243	1.17
2.1	Low material costs											3									420	3,82	756	3,65
2.2	Low manufacturing costs		1					1													456	4.15	804	3,88
2.3	Low transport costs		1					1													378	3,44	675	3,26
2.4	Low fitting costs		3	3		9		3	3		9				9						452	4,11	817	3,94
2.5	Low maintenance costs (long life, low maintenance expense)																				1110	10,10	2244	10,83
2.6	Low heating costs																				660	6,01	1371	6,62
2.7																								
3.1	Thermal insulation in winter											3	9								486	4,42	1008	4,86
3.2	Thermal insulation in summer																				3 %	3,60	774	3,74
3.3	Joint tightness											1	9		9						608	5,53	1199	5,79
3.4	Protection against driving rain																				432	3,93	900	4,34
3.5	Diffusion												3								372	3.39	804	3,88
3.6	Convection												3								102	0.93	219	1.06
3.7	Sound-proofing R'w,res > 43 dB																				228	2,08	498	2,40
3.8	Low longitudinal sound conduction																				228	2,08	498	2,40
4.1	Variable interior surface																				184	1,67	298	1,44
4.2	Variable conversion of loft space																				116	1,06	203	0,98
4.3	High degree of cosiness																				864	7,86	1818	8,77
5.1	No hazardous materials																				624	5,68	939	4,53
5.2	Recyclability				3	3				3	3										180	1,64	261	1,26
5.3	No health risks																				398	3,62	5%	2.88
5.4	Positive eco-balance																				180	1,64	261	1,26
	Significance for solution variants without target-group evaluation	5802	9018	1356	5148	8082	5802	9018	1356	5148	8082	5108	11268	1836	14184							100		100
	Significance for solution variants with target-group evaluation	10470	15993	2451	9207	14373	10470	15993	2451	9207	14373	9695	22932	3348	26442									

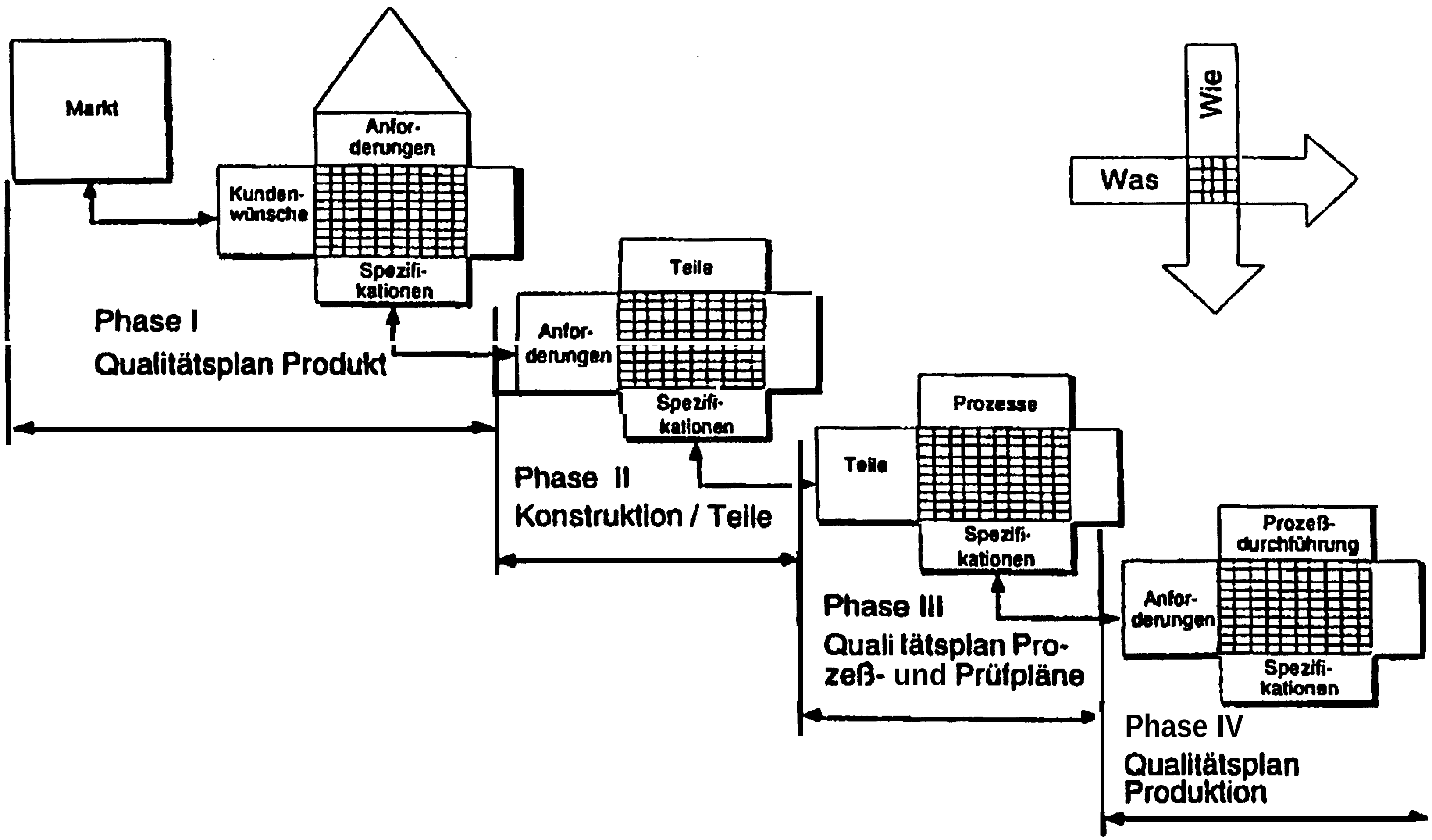

Fig. 1: Schematic presentation of the sequence of the QFD method

Sustainability Through Integration

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Abstract

To move towards sustainability in the built environment, environmental issues must become an integral part of the management systems of the organisation involved.

Taking action is one thing, moving in the appropriate long term direction is another. Without a clear strategic view of the relationship between construction activity, the built environment and society's goal it is difficult to focus action in a beneficial direction.

This paper puts forward a view as to how organisations' quality, health and safety and environmental management systems can be integrated, so that environmental issues do not remain on the barren periphery of organisational action.

The second part of the paper outlines a strategic view on the nesting of the parts set out above, drawing some conclusions for effective action in the future.

Keywords: Environmental Management, Integration, Improvement, Strategy

1. Introduction

Construction firms are increasingly faced with sustainable development-based requirements which are influencing many areas of their activities: ranging from proactive environmentally conscious design and construction, through to green marketing and asset portfolio management. These requirements are being generated by a diverse range of stakeholders who have an interest in firms' overall environmental performance: be it the growing public alarm about environmental depletion and degradation, insurance companies concerns over future liabilities centred on environmentally-hazardous land and building materials, or the emergence of green consumerism (for example, see [1]).

Environmental considerations are demanding enough for firms to manage – but they are coming on top of an existing proliferation of quality and health and safety issues. The question facing firms is whether to manage each of these requirement areas separately or to integrate and manage them as a single, cohesive system. It is argued that if sustainability (as well as quality and health and safety) considerations are to be truly promoted by firms, effort needs to be made to integrate environmental systems with other systems, and to align them with strategic direction.

It is proposed that integrated, developmental management systems is a useful means of addressing these issues. The paper is structured as follows. First, the prevailing responses to environmental, quality and health and safety requirements will be summarised. Second, the potentially adverse implications of these responses are articulated. Third, it is argued that an integrated, developmental system view is a useful way forward. Finally, a 'supple systems' approach is offered as means of operationalising this view in firms in a practical, meaningful way.

2. Prevailing responses

Corporate responses to environmental requirements come on top of existing efforts to actively manage quality and health and safety requirements. In a review of current mechanisms to manage these three issues Barrett & Sexton [1], concluded that:

- Quality requirements tend to be client-driven and are being addressed through the promotion of service or product consistency, rather than trying to cultivate continuous improvements.
- Health and safety requirements are predominantly legislation driven and are historically accommodated within firms through mechanistic systems, rather than culture-based systems which can integrate other, non legislation based, requirements.
- Environmental requirements are stakeholder-driven, a dimension which requires firms to create multiple perspective goals: a skill which many firms are failing to get to grips with.

Considering this apparently insurmountable mish-mash of requirement characteristics and organisational responses, it is temptingly easy to suggest that firms are doomed to be saddled with expensive and adversely fragmented management systems.

3. Implications for firms

The prevailing, fragmented systems have both effectiveness and efficiency implications. Bass ***et al.*** [2], for example, argue that such fragmented approaches encourage the following inefficiencies: actions and decisions being made in isolation (thus making them sub-optimal); employees being overloaded with information, and even with conflicting instruction which make open the firm up to risk; and bureaucracy.

In contrast, Barrett & Sexton [3] stress the risk of separate systems not being effective in two respects: lack of systems' alignment to overall strategic direction (shown in Figure 1 below), and lack of systems' appropriateness to engage and manage operational reality.

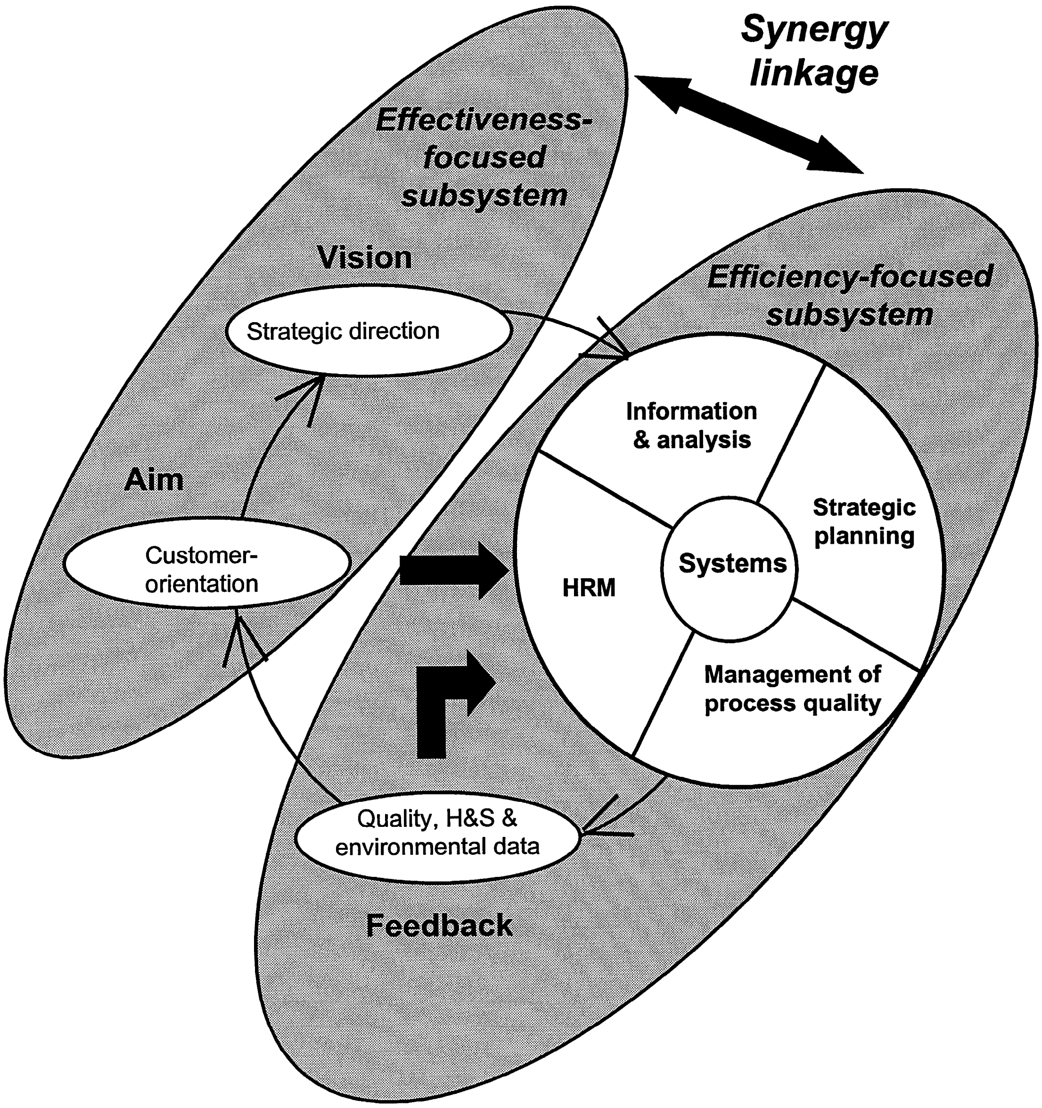


Figure 1: Aligning systems with stakeholder requirements and corporate focus

This leads to the central question in this paper: how can a firm enhance its environmental performance while also efficiently addressing the issues of quality and health and safety?

4. An integrated, developmental way forward

It can be seen that the complexity confronting firms provides a huge challenge and that the current approaches, or more recent developments, all carry problems.

The following section endeavours to effectively and efficiently 'nest' the management of environment, quality and health and safety requirements within an approach which focuses on the *improvement cycle* within firms. Thus, it can complement steady-state quality management / assurance, or be a viable option in the absence of such activity. It addresses an area where systems can contribute - the hinterland between individual action and corporate strategy - but does not pretend to address the whole of management activity.

It will be seen that the emphasis on key measures of tangible achievement fits well with the health and safety approach, at least as it appears in theory. In terms of quality there is increasing pressure to achieve improvements as well as consistency. In the environmental field this translates into an approach which allows incremental progress to be made toward meaningful action encompassing stakeholders' views.

It is suggested that the key to achieving improved organisation responses to a range of business requirements is to introduce balanced feedback mechanisms so that construction firms actually learn from occasions where it could have done better or from opportunities / ideas from other sources. This learning process is afforded by firms creating the capacity to scan, sense and monitor significant aspects of their organisational and business environments, the ability to link the resultant information to other information concerning the operating norms which direct activities, the ability to detect deviations from these norms; and the ability to initiate corrective action when deviations are detected. Furthermore, the feedback loops should encourage the capacity of the organisation to progressively improve through continuously learning, unlearning and relearning; rather than be geared towards the (eventually stagnating) maintenance of the prevailing system.

In simple terms, the construction firm collects positive feedback externally, as well as internally, then analyses the information and integrates it back into future service provision in order to improve performance levels. It should be stressed that the process is iterative and thus encourages continuous improvement, bit it must be strategically focused to avoid segmentation.

Further, the concepts of situational leadership introduced by Hersey *et al.* [4] might be useful in broadening this idea. These authors define the readiness of an individual or a group as a function of both ability and willingness, and argue that different management styles are appropriate to different levels of readiness.

The style depends on varying the levels of task and relationship components of leadership. Therefore it seems logical to expect the need for a stronger procedural approach to the implementation of environmental management in organisations that present lower levels of readiness, while for higher levels of readiness a more behavioural approach may prove itself more suited.

Based on this sort of thinking and aiming for systems which are client-responsive and facilitate a continuing cycle of improvements, an approach has been developed, through debate and observation, which endeavours to meet these criteria. The approach has been styled "supple systems" and is discussed next.

5. Supple systems

The supple system approach originated from the quality management domain (Barrett, [5]), but can be fruitfully enlarged and refocused towards the continuous improvement of how organisations address requirements generated from the business environment. The key features of supple systems are given in Table 1.

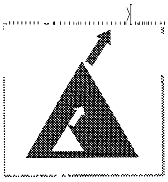
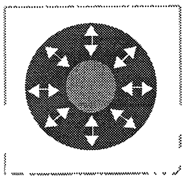
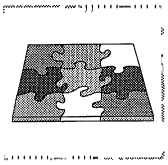
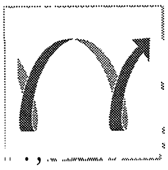
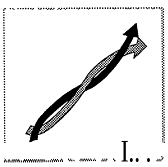
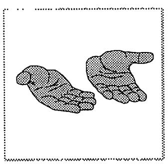
There is not space here to describe the approach in detail (see Barrett & Sexton, [6]), however, in summary, the approach advocates that a strong, but flexible *audit* system is developed which ensures that improvements in the quality of the service are being achieved. The audit system identifies sources of feedback, assesses if action is required, and at what level, prioritises between alternatives, allocates responsibility, checks later that action was taken, tries to objectively assess the impact of the actions and finally feeds these findings back to those involved.

In addition, action is required to be taken simultaneously on all of these fronts if construction firms are to be galvanised into enhancing their level of performance (see Barrett, [7], Barrett *et al.*, [S]). Firms need to create an environment in which people know what needs to be done to better support the core business. This is achieved through the *direction* provided at the strategic level which aligns systems with the core business strategy and with each other; by operationalising this vision through 'supple' systems which provides *information* about the level of performance on its full range of activities; and finally by underpinning these mechanisms by creating and supporting learning individuals and groups within an organisational context which encourages them to actively overcome problems and spot opportunities for doing things in better ways through *innovation.*

The objective, therefore, is to know what needs to be done, to know how to mesh individual actions to greatest effect and to have people involved who, once they know what is needed, are capable of, and motivated to produce, innovative solutions. The improved level of performance is the product of innovations, at all levels of the firm, each orientated towards clearly stated strategic goals by integrative supple systems. The end result of this enhanced dynamism is the creation of a continuously learning and innovating management systems that meaningfully contributes to organisational strategy formulation. The view presented here can be summarised as shown in Figure 2.

Although ultimately all of the above factors need to be working in unison to create optimum performance it is more realistic to think in terms of a sequential development. It can be argued that the feedback information is the first place to start as this will inform strategy formulation and begin to create a better informed customer orientation amongst staff. If, for a given organisation, say, a strategy already exists then this can be the springboard for the other areas instead. The particular order is not critical and is contingent upon the given organisation.

Table 1 - Key features of supple systems

Symbol	Feature	Description
	Objective-nested	The systems are aligned to, and positively support, appropriate strategic organisational obj ectives. Systems should not be developed within an operational/technical vacuum.
	Client / Stakeholder orientated	The systems are tested against stakeholder, and especially customer requirements, by actively seeking feedback through both hard and soft data.
	Minimalist / Holistic	"As much as you must, as little as you may", that is, not having systems for their own sake, but rather targeting high risk / gain areas. Better to have made some progress on all important fronts than to have patchy provision.
	Loose-jointed	The systems operate at an audit level: clarifying objectives, checking performance and integrating efforts. At an operational level different styles and approaches can be accommodated, especially when they have proved themselves over time.
	Evolutionary	Allow incremental and continuing progress to be made from whatever base.
	Symbiotic with social systems	Build on the norms and culture of the organisation, for instance allowing self-control or group pressure to operate where appropriate.

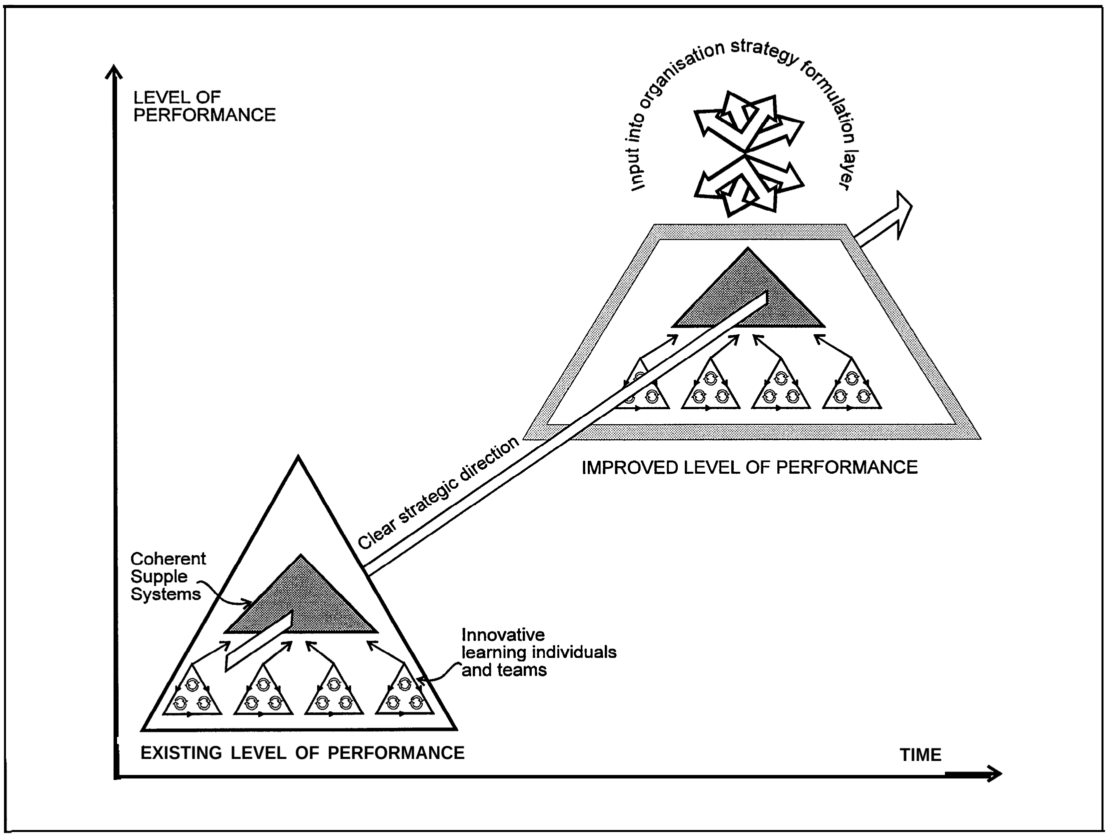


Figure 2 - Improving performance through vision and integration

6 Forces for and against integration

The level of integration of management systems seems to vary a lot along the life cycle of organisations. Small organisations tend to have a high degree of integration, accompanied by a low level of formality.

As organisations grow usually management systems grow more formal at the cost of integration. This movement is usually followed by an effort to recuperate the integration lost along the process. Different internal and business contexts may justify distinct choices regarding the degrees of integration and formality.

Multiple factors affect the degree of integration of management systems. Satisfying clients and other stakeholders should create a drive towards integration. Regulations and legislation will push towards highly formal systems, whilst costs will point towards the opposite direction.

The fact that the construction industry usually works with individual projects may play against integration, due to differing requirements.

The will of some organisations to show high profile initiatives to please specific lobbying groups may also play against integration, since there is a wish o showing neatly defined systems.

Low integration may also be fostered by lack of willingness, particularly due to the particular culture of the organisation, where an insular worldview may predominate.

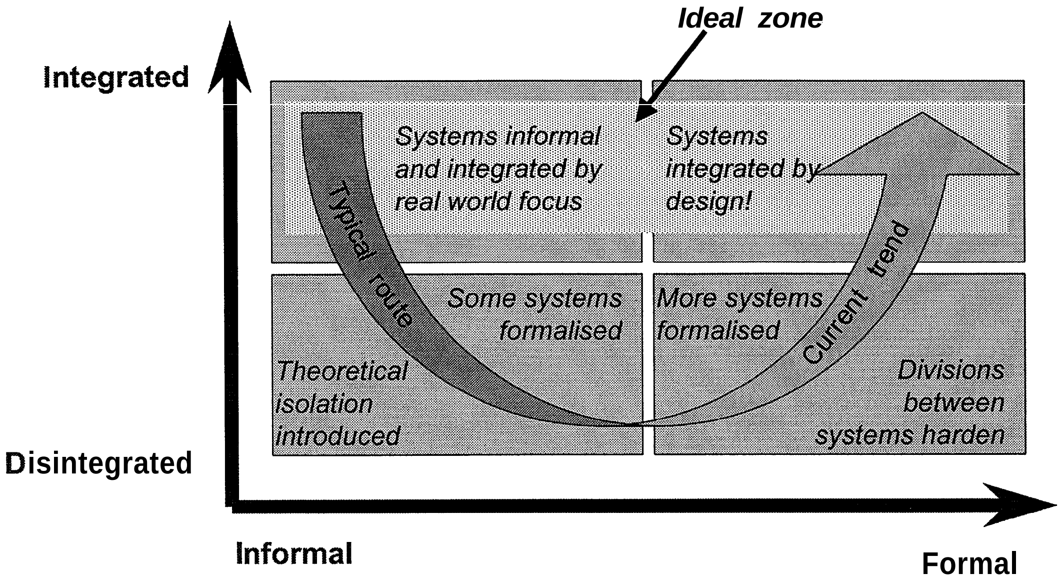


Figure 3 – Co-ordinating map

It is common to find environmental management system defined along the lines of *an organisation 's formal structure encompassing procedures, practices, resources and processes, that implements environmental management* (Griffith, [9]). We advocate that formality is not central to the definition.

Figure 3 is an attempt to summarise the current situation and propose an ideal approach. It seems reasonable to suggest a dimension running from informal to formal. There is certainly a lot of discussion about integration and so this implies the presence of its converse, namely disintegration. These two dimensions form the axes of the above diagram and allow the present situation to be illustrated very clearly.

Many firms have moved to create discrete systems, whether for quality, health and safety or environmental issues and have operationalised this in terms of formal systems. In doing so a degree of disintegration is achieved alongside the more focused management of the issue being addressed. This, then, is the "typical route" that has been taken. As more discrete systems are added the problems worsen leading to the emerging "current trend" which is for companies to seek to integrate those systems.

Arguably the response of, say, a small organisation could be effectively integrated by virtue of the fact that, although informal the firm addresses the various demands in an integrated way because that is the way they arrive as part of their workload. This could be just as appropriate as a very formal, but tightly integrated approach that might fit typically with the needs of a larger company. Thus, taking formality as a variable that is predominantly driven by factors such as size, it is suggested that there is an "ideal zone" where the response is integrated, but the level of formality can vary.

Overall, the model allows the suggestion of the ideal zone to be clarified and it highlights the potential inefficiencies of the current route being taken by many companies. If a firm does desire formal systems then the optimum route would appear to be horizontally across the "ideal zone".

Work is now being undertaken using case studies to investigate different parts of the above diagram and the routes between these parts.

7. Research agenda

Further work is essential to identify strategically relevant issues for construction. At the Research Centre for the Built and Human environment we expect to make a contribution through an ongoing project on integrated delivery systems for sustainability. The key issues for this project are:

- A definition of sustainable development
- Key performance criteria
- A coarse model of the major factors involved
- An understanding of the key interactions between these factors
- A map of relevant knowledge, so identifying major gaps
- A research agenda to support potential progress.

8. Conclusions

It has been seen that sustainability issues cannot be meaningfully internalised and acted upon within construction firms if they treat sustainability (along with quality and health and safety) as a discrete problem with an isolated solution.

Environmental performance improvement requires strategic focus if it is to flourish, and add real value to organisational performance. Without direction, environmental management systems and initiatives will always be on the barren periphery of organisational behaviour, because they cannot meaningfully influence it.

An objective-nested, integrated approach, in contrast, encourages beneficial mutual crafting between sustainability and corporate objectives. This permits the focusing of organisation-wide effort by guiding and shaping a climate where strategically aligned environmental improvement intent can emerge anywhere in the organisation, and be translated into performance-enhancing action throughout the organisation as a whole.

The focus should be embodied in a hierarchy of objectives that infuse and maintain a distinctive strategic theme throughout the organisation. The development of these objectives should take into account as many stakeholder views as possible. Further, these objectives should form the central measure for assessing environmental performance improvement; and, in the same breath, these improvement efforts should critically assess, and if necessary change, the substance of these objectives.

Solutions for environmental management should not be taken at face value. The relevance of each approach should be judged per se, but only within the context of each firm and its environment. However, sometimes the approach followed may suit better the interests of the consultants selling it, rather than the company where it is actually implemented.

9. References

1. Barrett, P. & Sexton, M.G., (1996), “Explosive Management: Destruction or Propulsion”, **The Organization and Management of Construction: Shaping Theory and Practice** (vol. 1), pp. 13-22, E&FN Spon, London.
2. Bass, J., Gill, M., Guzman-Bello, J., MacFarlane, A. & Parsons, M., (1996), **Integrated Management,** Society of Motor Manufacturers and Traders Limited: London.
3. Barrett, P. & Sexton, M.G., (1998), “Integrated Management Systems: Fieldwork Report”, **CIC/DETR Integrating to Innovation Project,** University of Salford: Salford
4. Hersey, P.; Blanchard, K.H. & Johnson, D.E. (1996), **Management of Organizational Behavior - Utilizing Human Resources,** 7th Ed., Prentice-Hall International Inc, Englewood Cliffs (New Jersey).
5. Barrett, P., (1994), ‘Supple Systems for Quality Management’, RICS **Research Paper Series,** RICS, London.
6. Barrett, P. & Sexton, M.G., (1995), ‘Integrated Management Systems’, **Proceedings of the COBRA ‘95 RICS Construction Research Conference, 8-9** September.
7. Barrett, P. (Ed.), (1995), **Facilities Management: Towards Best Practice,** Blackwell Science: Oxford.
8. Barrett, P.; Sexton, M.G. & Stanley, C., (1995), ‘Cultivating Continuous Improvements in Facilities Management’, Paper presented at the **COBRA ‘95 RICS Construction Research Conference,** 8-9 September.
9. Griffith, A. (1994), **Environmental Management in Construction,** MacMillan, Houndmills.

What Do We Mean By Sustainable Construction?

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Abstract
It is no longer tenable to do other than seek sustainable development strategies, given that the alternatives are unsustainable development or no development at all. Serious debate is focused on the pace, and means of achieving sustainability and how it might be measured and targeted. The environmental performance of the construction industry is a cause for concern.

Buildings have a crucial impact on the physical and economic health and well-being of individuals, communities and the organisations which they are intended to support. They should enhance our quality of life. Yet they frequently contribute to ill-health and alienation, undermine community and create excessive financial liability. Modern planning is innately socially divisive and environmentally exploitative. Transport energy consumption is influenced both by planning policies, where they mitigate against mixed use development, and by the aesthetic and environmental poverty of much of the built environment which provides the impetus to travel. Out of town retail, business and science parks pass costs onto consumers and employees, encourage a culture of pollution and disempower non car-owners.

The Brundtland Definition of Sustainable Development talks about meeting the needs of the present and those of future generations [1]. Children born now may be alive in the 22nd Century and spending the greatest part of their lives, up to 90 per cent in industrialised nations, within artificial enclosures, just as we do today. They will not expect their buildings to constrain them as individuals, or communities, but to enhance their well-being, be functional, efficient, joyous and healthy. These are basic rights of individuals and basic needs of a society. There are examples of beneficial innovation, but the reward structure mitigates against the concern, ingenuity and resourcefulness which exists.

It is necessary for everyone involved with the construction industry to recognise the role of buildings and the extent of our responsibilities in creating a sustainable built environment. The paper will examine, through case studies at all levels, the cultural problems of the construction industry which have brought us to the present condition of 'a defensive response to a hostile environment'; to resource dependence and consequent ingrained pollution and to irrational responses. The case studies indicate both the contemporary dangers of the changes which are now required and a way forward to an improved, sustainable built environment for industry, commerce and building occupiers. It will become clear that if we are to contribute to the Brundtland objective the process of change can and must start immediately.

Keywords: Sustainable construction, culture shift, case studies, inter-generational, construction process, subsidiarity

1 Fragmentation

"How long can we pretend that the environment is not the economy, is not health, is not the prerequisite to development, is not recreation" C.Caccia[1]

1.1 Inside from outside

Over a period of time we have separated the inside of the building from the outside and made it the responsibility of the services engineer. In the past, buildings often made good use of microclimate, orientation, sunshine, natural light and air. The rapid growth in building services technology in the 1960's encouraged architectural vision to be context free. There has been an increasing tendency to replace natural systems: sun, shade, sensible cooling, natural light and air, building form and fabric, with energy consuming mechanical and electrical building services which are frequently more prolific than necessary, often difficult to operate economically and which create external local and global pollution. Designing within available limits is rarely perceived as a creative engineering challenge, generally it is not considered at all.

Design is driven by extremes and error margins, leading to oversizing and inefficiency under most circumstances, and ultimately making them difficult to operate economically, to meet real user needs, requirements and aspirations. These technologies present an ongoing burden with respect to running costs on a short term replacement cycle, which makes them a much more substantial aspect of the life cycle cost than is apparent from present emphasis on capital cost. Mechanical systems can also contribute to poor air quality, requiring yet more technology to resolve and adding to the vicious cycle of degradation. Yet, simpler and environmentally more benign solutions are often possible, with services operating as efficient supplements to natural systems rather than as substitutes. Passive ventilation, lighting, heating and cooling techniques have been developed in the last 20 years, which offer major unexploited opportunities in new and refurbishment situations. Much could be achieved by serious attention to traditional techniques, innovative development and contemporary knowledge, which may differ from conventional wisdom.

1.2 Buildings from location

Buildings have been removed from their climatic context. Because of the availability of fans and pumps and wires we now have a global architecture with little attention to the external climate or the availability of local resources, including human skills. Globalisation means designers can have identical facades or identical buildings climatically thousands of miles apart.

1.3 People from building

The underlying problem of using over-simplistic thermal standardisation is only slowly being unravelled. As clients were led to believe they could have universal comfort; environmental engineering became disassociated from building occupants as well as architecture and climatic context. But expectation with respect to building temperature continues to rise, bucking the laboratory mannequin. Standardised comfort design criteria sanctions 20% thermal discomfort within any interior. We should be wary of recent moves to standardise air quality.

1.4 Technology from people

We have increasingly separated technology from people by removing personal control and yet we have found that technology choice has a potent human dimension. We need to seek design solutions which rationalise building control and management to the available skills.

1.5 Product from process

We endorse fragmenting the professions and make the architect God of the pristine vision and the services engineer and supply chain the servant of its resolution. Division has encouraged us to forget that construction like creation is a process not an act. The design process traditionally stops at completion and encourages a fit and forget maintenance-free culture ignoring the downstream implications of design. Maintenance free means unmaintainable.

1.6 Us from them

It is difficult to know who to blame in the design process and the scapegoats are all too often the environmentalists. By fragmentation we have pursued Einstein's dictum that the environment is everything which is not me. But Einstein was wrong. Good air quality, clean and adequate water are the responsibility of the engineer.

1.7 Synthesis

Handy Hint No. 1: "Only connect*'

There is a move to break down the barriers and examples given will span the development of interdisciplinary design teams, process management documents which professionalise environmental design, formalised feedback such as PROBE, technical developments such as breathing walls, dynamic insulation and natural ventilation, flexible comfort bands with user controls.

2 Inertia

"If you are not part of the solution you are part of the problem"
Eldridge Cleaver[2]

2.1 Feedback

Handy Hint No 2: Use the precautionary principle

Precautionary action begins with learning from our own experiences and those of others. If we suspect a problem, or can envision a better solution, we should deal with it constructively and not talk it down. Every aspect of construction has a consequence which needs to be processed to aid future decision making. This requires feedback from buildings in use and innovative techniques. Feedback is a crucial part of any design and management process, and yet the UK's architectural and engineering work stages stop at completion. Feedback should aim to identify how good ideas in theory work in practice, and identity the most effective and cost-effective opportunities for significant improvement, to ensure that responses are adequate. All new building, and existing building management or demolition, needs to be undertaken with a view to minimising the long term liability of a building and its components. The challenge is inevitably context dependent and only rarely will there be 100 % right answers.

The argument against the precautionary principle tends to be that preemptive action is expensive, stunts beneficial innovation and may be unnecessary: Basically that now is optimal.

2.2 Delay

We are familiar with the global warming figures such as those expressed by the UK and other governments.[3] They are not very different from figures published in children's books in 1972.[4] Scientists investigating the effects of CFC's identified a problem with stratospheric ozone depletion in 1974.[5] Work in 1990 identified 25% of energy use in buildings could be saved cost effectively.[6] Research on life cycle analysis of buildings has highlighted the life cycle costs which make an absurdity of first cost accounting.[7] Yet this information has made only marginal differences to design activity and emissions from service systems are now the biggest single source of UK CO, pollution, and increasing faster than any other sector.

Handy Hint No.3: Try being an environmentalist for one hour a week. It won't hurt

2.3 Analysis Paralysis and Other Impediments

When we feel constrained we are good at creating further problems to solve. For example:

- sealing buildings to save energy and adding yet more building services to provide adequate conditions appears to have led to an increase in sick building syndrome and energy consumption has remained steady;
- adding layers of complexity to controls means that all too often expensive and impractical safety default mode is normal and not-evident except to the highly specialised eye.

Public recognition of the seriousness of environmental issues is accompanied by:

- It is not surprising that at a time of crucial change, too much time is being spent on combating misinformation; diluted marketing responses, unproven environmental claims and trivialisation; advertising is on the basis of any convenient element such as durability or energy efficiency without justification.
- genuine complexity requiring in depth knowledge is circumvented by bureaucracy such as environmental management systems which can readily create paralysis by analysis - without genuinely addressing environmental priorities.
- Professional environmentalism is welcome and long overdue but there is a danger that experience is being ignored with the consequences that errors made by amateurs are being repeated by professionals leading to a better quality of error!

- life cycle analysis dominates the pragmatics of a life cycle approach.

Examples will indicate a range of contemporary traps in the move towards implementation of appropriate strategies.

Handy Hint No. 4: Committed and meaningful action on all fronts

3 Tokenism

There is a mix of proactive implementation accompanied by half-hearted approaches and opportunist responses which may inoculate us against genuine and effective solutions. The futuristic green visions are emerging, and where they rely on the old theory of control and beating nature into submission they should be treated with scepticism. Examples will indicate a range of fantastic solutions and tokenist, impractical and expensive measures.

We now have a pretty good idea of the nature of the problems facing us and we need to design real solutions. Fortunately there are members of the construction industry who have pro-actively sought to offset what they believe to be risks and they deserve our respect and support.

4 Some Elements and Their Integration - Draft examples

Decision making may appear as a complex and difficult task, but professional are required to make decisions as a matter of course and the incorporation of environmental concerns is now a fundamental requirement. Environmentalism is now legitimate and professional assistance is available and there are simple principles which can be followed at a strategic level which will assist us to slow the rate at which we approach the carrying capacity of the earth.

Examples from a range of buildings indicate what can be achieved through:-

Replacement Materials & New Technical Opportunities

Insulation

A manufacturer initially disguised the fact that this insulation material was made from recycled newsprint because they thought that people would consider it an inferior product. It is now a thriving business and the hygroscopic properties of the material have opened up new technical options:- not least breathing walls (now in the Building Regs) and dynamic insulation.

Dynamic Insulation

Dynamic insulation seeks to break down the barrier between the inside and the outside, the services and the architecture. We are increasingly familiar with the notion of building physics but less so with building biology in which the building is an interactive membrane like our skin, like modem sports clothing. Dynamic insulation is being used in a sports building in Callander. It uses the building fabric as an active part of the ventilation system by creating a pressure differential through natural or mechanical means. The air is drawn through the porous membrane which operates as a buffer and reduces reliance on mechanical plant reducing stratification, air change rates and toxicity levels. [8]

Appropriate Components

Double glazed windows were not traditionally sealed, this only happened as a response to specialist gases. Over a period these have become packaged as maintenance free units. But maintenance free invariably means unmaintainable and either dramatic failure or fashion obsolescence. There is evidence that gas-filled window systems have failed after quite short periods of time and a Norwegian designed a triple glazed window which performs well in the long term, costs the same as a double glazed unit and is maintain able. [9]

Clean Energy Technology

Solar Air Conditioning

Desiccant cooling technology, which uses low temperature heat, opens up the potential for solar air conditioning (a/c). Given the predicted rise in the need for a/c it seems ecological and serendipitous to combine these techniques while we determine a better long term strategy. [10]

Passive Solar Design

A range of new and refurbishment projects which utilise passive solar design. [11]

Renewable and Hybrid technologies:

Projects which source their energy from local and renewable sources including wood chip boilers. [12]

Burner Technology

Regulatory response to acid rain was swift and there has been significant innovation amongst boiler and burner manufacturers.

Materials

Detoxification .

Non-Chemical Treatments- Architects called upon to chemically treat loft timbers for insurance purposes worked with a consulting company to develop a ventilation system which would ensure that the beams were protected. They got insured, breaking the unholy alliance between the chemical and insurance companies, and saved significant amounts of money.

Benign Specification- Materials and finishes [13]

Materials Audits- Most products and processes were designed before environmental issues were fully under stood and process studies are able to identify cost effective efficiency measures to reduce energy use and chemicals.

Clean & Conservative Water Strategies

Water Management Technology

Living machine as a biological waste treatment cycle.

Reed Beds

Composting

Community

Agenda 21

When faced with the prospect of a major refurbishment, Oxford County Council decided that they wanted to make the best of new knowledge developed in the intervening 30 years. They looked at adaptive comfort theory, energy efficiency and personal control issues and decided to try openable windows, which they did to a small degree under experimental conditions. The occupants expressed a prefer in a city centre site for openable windows despite the external noise and possible air quality issues. One might have assumed that they would then be concerned that conditions in the urban environment could get worse. Yet they turned to the local authority Agenda 21 strategy, the commitment to continual improve, to justify their decision for the long term. [14]

Handy Hint Number 5: Audit your product or service for cost-effective environmental saving Now is not optimal

Handy Hint No.6: Process the consequences of expediency

Handy Hint No 7: Reconsider Darwin who described evolution as survival of the fittest

Nothing lasts for ever but successful evolution involves the ability to diversify quickly and decisively in response to changes in circumstance. Survival rests not with the fittest but with those who are most fitting

5 Intergenerational Solutions

"It is an injustice, a grave evil and a disturbance of right order for a large and higher organisation to arrogate to itself functions which can be performed efficiently by smaller and lower bodies." Quadragsillo Anno [15]

Sustainability isn't just about the environmental ether. It is also about social fabric and value systems, about educating children who can educate their children, building lasting communities, enhancing the world and not neglecting it. It is about developing permanent cultures with an ethos of continual improvement. It is about dignity. The UK commitment to sustainable development has been translated as 'intergenerational responsibility', and it seems appropriate that initial planning for a long term development should have the participation of the eventual users. The Brundtland definition refers to "development which meets the needs of the present without compromising the ability of future generations to meet their needs". We should remember that we are still far from meeting the needs of today. In many areas, poor quality housing and schools, lack of amenity, poor transport infrastructure and high unemployment, combined with lack of investment and vision have conspired to create low expectation, low achievement, state and utility dependence and atrocious environmental performance.

By involving children in the planning process for a major development in Edinburgh it became clear that they are very discerning, they want safe areas, jobs, good quality housing, soft and clean technology, wildlife corridors, schools that didn't leak, a children's parliament, everything we are failing to provide. If we expect children to be good citizens shouldn't we be respecting their genuine needs and desires. What can we expect from them when we display bad stewardship and give them so little of lasting quality.

If we are successfully to implement Agenda 21, then experienced consultation and planning strategies are required to transform these estates, which present major opportunities for benchmarked improvements from net sinks, to balanced, safe, healthy and productive communities of the future.

6 Building In Solutions

"Creation is not an act but a process" Theodosius Dobzhanskey [16]

Construction activity extends from inception to demolition and beyond to recycling of components. Decisions at each stage will positively or adversely effect the economic, social liability and ecological impact. Buildings generally last a long time and badly designed buildings inflict unnecessarily high demands on the environment and are a poor legacy for future occupants and future generations. If they are demolished prematurely they represent a wasteful use of capital and human resources and embodied energy and water. Building components are increasingly indestructible composites. As well as embodied energy and embodied water and pollution, we also see the rise of embodied disposal cost.

But the most important decisions, affecting the impact of a building, are taken at the earliest stages in building conception and design. Unfortunately, the tendency remains for the architect to design and the engineer to service with minimal regard for issues within their grasp to influence.

Less than ideal buildings result from poor communication between the disciplines and their differing priorities, yet everyone could make a constructive contribution. Procurers can achieve a great deal by establishing a brief within an ecological context and by moving away from the unhelpful syndrome of lowest capital cost and supporting design selection and plant procurement on the basis of life cycle cost and environmental impact. Similarly, designers must learn to think about passive systems and issues leading to over design and inefficiencies.

They should pay attention to detail and give forethought to manageability, and the needs, requirements and aspirations of users. Cost professionals need to find mechanisms for integrating architecture, structure and services strategies on the basis of life cycle costs. Professional institutions need to lobby at high level for sensible pricing policies and appropriate fee structures which respect society's needs and the wider environment. They need to promote life cycle, passive and inter-disciplinary approaches to design and material selection, while setting responsible strategies for seeking genuine solutions and combating misinformation. (contractors and suppliers can contribute by minimising wastage, pollution, hazard and risks associated with their products, services and working practices. Even quick look audits can identify cost-effective environmental opportunities for improvement. Owners and occupiers could assist by sound management and seeking continual improvement, while everyone could assist by recognising and pursuing quality.

7 Culture Shift

"Infinite growth on a finite planet is an impossibility." Fritz Schumacher [17]

We have been encouraged to believe that consumption is a measure of success, yet it is increasingly evident that the ability to meet social goals with the minimum use of resources, and minimum waste and pollution, is the mark of a successful society. The main requirements are not for increased complexity, but for more care and forethought, more attention to the environmental impact of material and energy supplies and more focus on the genuine needs of organisations and users.

We cannot continue to divide the responsibility, perpetuate the inertia, respond with tokenism or invent more problems. We need a discerning reward culture and truly inter-generational solutions.

A culture shift is fundamental to the pursuit of sustainability, and the direction of this shift is becoming increasingly evident. The common features are a move from the scientific, reductionist world view to a holistic world view which began with Fourier and Owen and was developed into an applied human ecology by Geddes. Ultimately the question must be "what kind of built environment do we want?" What can we expect from subsequent generations when we have created so little of lasting quality and value?

It is traditional to read Darwin's 'survival of the fittest' as the biggest, the boldest and the strongest. But it is becoming increasingly clear that survival is the domain of those most fitting in the face of ecological limitations, to which we must all ultimately defer.

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References

1. Caccia, C (1987) Our Common Future: the Brundtland Report, *World Commission on Environment and Development.,* Oxford University Press
2. Cleaver, E. (1974) in *Design* for *the Real World* (V.Papanek). Granada
3. *HMSO* (1990) *Review of the Potential Effects of Climate Change in the UK,* HMSO
4. (1972) Ecology, Cycle and Recycle, *Basic Biology in Colour,* Vol. 5, Kolbas
5. Meadows D.H., Meadows D.L., and Randers. J. (1992) *Beyond the Limits: global collapse or a sustainable future.* Earthscan
6. BRE (1990) *Energy Use & CO2 emissions from UK buildings,* BRE
7. Halliday, S.P. (1995) Setting out a clear framework: in the age of consequences. *Teaching in Architecture Energy and Environmental Network,* Florence.
8. Liddell. H., Roalkvam, D. & McKenzie I. (1996) *Dynamic Insulation* CIBSE Technical Conference, CIBSE
9. Halliday S. P (1997) Architecture of Habitat - Design for Life Phil. *Trans of the R.Soc*
10. Halliday S. P. (1998) Solar Desiccant Cooling, Warwick University
11. ETSU *(1996)Passive Solar Design in Non-Domestic Buildings,* ETSU
12. Gaia Group (pending) *Glencoe Visitor Facility Project Report*
13. Halliday S.P., Liddell H.L. *(* 1997) *Environmental Labelling of Building Materials,* IF1.
14. TASC Agency (1997)*EcoCity* Craigmillar EcoCity Project Video, TASC
15. in Handy. *C.* (1994) *The Empty Raincoat* Hutchinson
16. Weiner J. (1995) *The Beak of the Finch* , Vintage
17. Schumacher E.F. (1973)b *Guide to the Perplexed,* Abacus

Environmental management in Denmark from development programmes to practice

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Abstract

In the Danish building sector, environmental management is currently being implemented in three areas: design, construction and operation of buildings.

This innovation is based on development programmes which have been completed in the last few years. Dissemination and incorporation of the results of these programmes are being closely monitored.

Common to all the development programmes is a requirement that building clients and companies formulate an environmental policy describing attitudes, goals, priorities and organisation.

The next step in the individual building projects is an environmental review to map environmental factors. This is followed by an environmental action plan as the basis for start-up of environmental management.

Lastly, environmental audits are carried out to check that the environmental management system works properly and that the goals are being achieved.

Environmental management in the three areas in question: design, construction and operation, is based on these elements. In practice, environmental management differs in the three phases because the content and the parties differ from phase to phase.

Key words: Sustainability, environmental management, design, construction, operation.

1. Environmental management - why?

The move towards sustainable building has long been characterised by a major effort to save resources - energy, electricity and water - during use of buildings.

However, the possibilities for environmental measures have grown and there are probably now between 100 and 200 available to use - a veritable ecological supermarket.

To get a better and more complete picture in each building project of the best solutions there is a need for systematised, interdisciplinary analysis of the various options.

For this reason, three development programmes have been used to develop new methods of management and control of the design, construction and operation of buildings. The methods in question give greater priority to integrated assessment of environmental impacts from new buildings and from the operation of existing buildings.

Environmental management is built up around four basic elements, which appear in all three programmes.

Building clients and companies must formulate an environmental policy aimed at continuous improvement of environmental performance, firmly placing responsibility and authority and laying down goals and guidelines for monitoring of the results.

An environmental review maps the environmental factors, measured - for example - by impacts on resources, the surrounding environment and people. The next step is an environmental action plan, containing an activity schedule and time schedule for the actual environmental work, with responsibility, authority and environmental tasks assigned in accordance with the environmental policy.

Environmental audits are the means by which it is checked that the environmental management system is working satisfactorily and that the targets set have been achieved. The audits can be used as the basis for an environmental performance report, making the results achieved public.

2. Design - the first step

The first step towards better environmental management is new design methods.

In Denmark, a development programme for “Environmental management in project design” was finished in 1998.

In accordance with this programme every building project should start with mapping of the relevant environmental factors. The most appropriate and financially advantageous measures will naturally depend on the local situation.

It is important to carry out an integrated assessment of the possible areas for action.

The programme differentiates between impacts on our resources (what is removed), impacts on the surrounding environment (what is added) and impacts on people (during construction and later operation). The impacts can be reduced by various means, such as choice of materials, ensuring replaceability, reuse/recycling and substitution.

The building client must therefore ensure that an integrated interdisciplinary analysis is carried out to pinpoint the main - say 1 O-1 5 - environmental factors to which particular attention must be paid in the performance of the project.

The design work must be based on the chosen areas for action. In other words, an environmental policy must be drawn up and environmental objectives specified for the building project in question. This must be followed by an assessment of the consequences for the design of the building, including the choice of structures and installations.

The new design practice is thus based on cooperation between the building client, the architect and the consulting engineers on the formulation of an environmental programme based on the environmental objectives.

The next step is to draw up an environmental plan showing how the programme is to be fulfilled in practice. Lastly, the environmental action is documented in an environmental balance sheet.

The environmental objectives may, for example, include the building's relationship with its surroundings, its resource consumption, lifetime, maintenance, reuse/recycling potential, working environment, energy consumption and indoor climate.

For example, special solutions may be chosen - form of ventilation, materials, surface treatments and sun-screening - that fulfil the requirements with respect to indoor climate. Quality assurance and environmental management go hand in hand here - quality assurance ensures that the environmental objectives are achieved.

In connection with the development programme a database is being established with general environmental information on all main building materials and a guide to gathering specific information from manufacturers.

3. Environmental management at the building site - second step

In the construction phase, too, there is a need for systematic monitoring - for example, of the consumption of energy and water, handling of waste, noise, odour problems and dust.

A couple of examples will suffice to show the importance of such monitoring: transport in connection with building and civil engineering work accounts for about 45 % of Denmark's total transport of goods by lorry, and the building industry accounts for 3 % of Denmark's total energy consumption.

There are at present three main standards for environmental management: the British Standard BS 7750, the EU's EMAS Regulation and the international standard IS0 14001.

In a Danish development programme called "The Contractor's Environmental Guide", a compendium of information material has been put together as support for the introduction of environmental management at contracting firms. The material, in the form of booklets, guide, eco-file and a video, is addressed to different levels within the contractor's organisation.

During the performance of a project, quality assurance and environmental management can be integrated and taken care of in two ways. Firstly, the building client must ensure that the agreed quality is achieved in the chosen areas - cf. above on indoor climate - and, secondly, the contractor must monitor the work at the building site with respect to its environmental consequences - waste, noise, odour problems, dust, etc. - as mentioned above.

4. Environmental management during operation - the third step

The basis for the operating plan is the owner's aims with respect to the exterior appearance of the building, the building's indoor climate and other utility functions, its energy consumption, and its state of maintenance.

It is natural to integrate environmental factors with the operating plan. In the above-mentioned example concerning indoor climate, the points mentioned - ventilation, materials, surface treatments and sun-screening - must thus be included in the operating plan

It may be appropriate to go one step further, since studies of resource consumption during operation of buildings show big differences from one housing unit to another, and experience with reduction of energy consumption indicates clearly that awareness and motivation on the part of the occupants are absolutely essential for achievement of a lower consumption.

Mapping the actual consumption in a housing unit or an apartment building, for example, and information about what other households use - possibly what the best **30 %** use - enable the occupants to opt for a given consumption - low or high.

In the Danish programme "Environmentally Managed Building Operation", a new approach to operation has been developed.

According to the resulting guidelines the consumption is mapped, the occupants choose an objective for the building's future consumption, and an action plan is drawn up for achievement of the objective.

The most obvious areas for action are consumption of energy, water and electricity and handling of waste. In these areas it is relatively easy to record the consumption. In the longer term, it may become relevant to include other areas, such as indoor climate and noise level.

In other words, integration of quality assurance and environmental management in this area means both achievement of the objectives set up in the design phase and continuous assessment of the operation of the building, with the possibility of improvements.

5. Conclusion

The new methods for environmental management make it possible to work with environmental factors in a more planned and systematic way.

Experience from the Danish development programmes show:

(1) That environmental management should be integrated with <u>the normal work</u> processes
(2) That environmental management should be carried out in a <u>close cooperation</u> between all the parties involved in a building project
(3) That environmental management should be planned so that the work follows the normal, <u>progressive decision-making process</u> in a building project
(4) That environmental management should <u>start as early</u> as possible and be both interdisciplinary and long-term
(5) That <u>prioritisation</u> is essential and that the most serious problems must be kept in focus

(6) That environmental management should be visible all the way through - from the design phase, through the construction phase, to and including the operating phase

In the years ahead, Danish building firms are going to have to incorporate the principles for environmental management. In the long term, this will result in a shift in the way building clients and firms work in the direction of sustainability and will also bring financial advantages.

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A practical approach to life-cycle economy

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Abstract
In the financial management of housing projects, the main focus of attention has traditionally been the construction costs. In recent years, however, the view has evolved that account should also be taken of the subsequent operating costs. In Denmark this has led to a new law requiring a life-cycle cost assessment in connection with the planning and design of subsidised housing.

A housing project's life-cycle cost include a capitalisation of the total cost of construction and operation during the life-cycle of the project or for a specific period of time. The operating costs comprise maintenance, cleaning, electricity, gas, water and heating, and general operating costs, such as caretaking, taxes, insurance and charges.

A life-cycle cost assessment makes it possible to balance the construction costs against the operating costs. For example, different installation solutions can be assessed on the basis of the total cost, i.e. the combined cost of construction and subsequent operation. The same can be done in the case of structures and surfaces.

A life-cycle cost assessment could thus lead to higher construction costs if it showed that this would result in savings in operating costs that exceed the extra investment.

However, this type of assessment could also indicate other benefits - relating to environmental aspects, for example. Improvements in this area could thus be deemed worth some extra investment.

In connection with the new act, the Ministry of Housing and Building has had a special PC program designed by the consulting engineers Birch & Krogboe. The new program provides a simple means of carrying out a life-cycle cost assessment of a housing project.

In this connection, the Ministry has launched a development project aimed at facilitating assessment of the sustainability aspects in connection with the life-cycle economy of housing projects.
Keywords: Life-cycle economy, PC program, sustainability.

1. The basis

Life-cycle cost assessment implies estimation of the uncertainties and future risks involved in the development of a project's operating costs.

In the last 5-10 years methods have been developed for life-cycle cost assessment. In Denmark, interest has focused on calculation of the net present value, in which the operating costs are discounted to the time of construction and added to the construction costs, cf. the reports mentioned in the references.

The main features of the new PC program are as follows:

When a few values for the locality have been entered (such as supply prices in the area in which the planned project is going to be situated), together with the size of the project, both the construction costs and the total life-cycle economy of a reference project can be calculated. The calculation is based on the known costs for the construction and operation of traditional housing, Here, traditional should be understood to mean that the structures, installations, surfaces, etc. are in line with normal practice for low-rise and high-rise housing.

In the next step, data are entered for the planned housing project. This is done by altering the data for the reference project - although only the items where the planned housing project differs from the reference project. The program then computes the construction costs and life-cycle economy of the planned project.

The uncertainty of the calculations is given for both the reference project and the planned project. A full analysis of the proposed solutions in the planned project is then carried out in which account is also taken of architectural and environmental factors.

In order to design a program that is simple to use in practice it has been necessary to make a number of assumptions concerning such matters as lifetimes, inflation and return on investment. This input is thus not based on actual calculations.

Use of the program in a number of experimental housing projects will be monitored for one to two years as a basis for determining its usefulness.

One of the problems of life-cycle cost assessment is the uncertainty of the operating data. The work of gathering experience in the various operating areas is therefore going to be intensified.

Life-cycle cost assessment in connection with planning and design provides a better basis for assessing the construction costs and the general quality of a housing project. However, it is also important to carry out a critical review of the computed values.

2. Calculating principles

The calculation of the construction costs for the reference project is based on a chart of accounts with 65 items, largely in line with the SfB-system's table of building components. For each building component, values are specified for minimum, maximum and probable cost, corresponding to the 10% fractile, the weighted mean value and the 90% fractile.

For these 65 items, the cost of maintenance is also calculated, as a percentage of the construction cost, and upkeep (planned maintenance), as a percentage of the construction cost, taking into account the estimated lifetime of the building component in question. The above-mentioned fractiles are also used here.

Cleaning costs are included in the maintenance costs.

29 items relate to services (electricity, gas, water and heating) - e.g. heating of apartments, consumption of hot utility water and losses in connection with heat production.

The service costs are based on standard key figures for consumption and information concerning local supply prices (which are entered by the user).

Lastly, there are general operating items, which include caretaking duties - snow clearance, care of technical installations, stair-washing, etc.

The figures for general operating costs are given per square metre floor space and are based on experience.

In the calculations for the reference project, account is taken of the fact that the prices for both construction work and operation can vary from region to region, cf. below. The actual location and the actual supply prices must be entered. Data are also entered concerning the size of the planned housing project, the number of dwellings, etc. The result is thus a reference project that corresponds in size and location to the planned housing project.

The program computes the life-cycle economy and net present value, total and per square metre, for the reference project.

The planned project is then modelled as changes to the reference project. The construction costs for the various building components are given as a percentage of the total cost.

For maintenance, the percentages can be changed correspondingly. For example, the extra investment needed for energy-saving measures could be offset by a gain on the supply side. However, the extra investment might also imply bigger costs for maintenance, upkeep and general operation (caretaking).

For the operating costs, changes can be made to the quantities for consumption and the cost of upkeep (by changing lifetimes) and to the general operating costs (by changing prices). It is important to carry out a realistic assessment of the operating costs of new solutions. For example, special fittings may considerably reduce consumption but also require better care. That may demand more of the tenants.

The program uses a 30-year period, a nominal interest rate of 5% for estimating purposes and a rise of 2% in the price of services.

The lifetimes used for materials are based on available information.

In addition, various assumptions are made concerning both construction and operating costs. That applies, for example, to water consumption per tenant, number of tenants per dwelling, consumption in communal rooms, heat and electricity consumption, and waste.

It is estimated that it takes 10-20 hours to run the program in.

The program can also be used for the individual building components, keeping other factors constant.

3. Application in practice - examples

Before publication in January 1998, the program was tested on some planned housing projects.

One of these projects is a sustainable housing project in Aarhus, which is one result of the Danish Minister of Housing and Building's action plan for sustainable housing. A similar project, based on the same general principles, is under construction in Ikast.

In the computation of the planned project, the following construction items were changed because of special environmental measures:

Heating installations in the apartments (due to solar heat system), fans (due to ventilation system), fittings in the apartments (due to CTS-system), windows and doors (due to super-insulating glazing), and stormwater pipes by buildings (due to reuse of roof water).

These extra investments result in a total increase in construction costs of DKK 721 per m^2 floor space.

The extra investments result in changes in the operating costs for the planned housing project in relation to the reference project. The changes concern the following:

Cold utility water for apartments (water saving due to use of roof water), heating of apartments (heat saving due to solar heat system, ventilation system, CTS-system and super-insulating glazing), heating of apartments (operating costs for the said systems), power and lighting in apartments (operating cost as a consequence of the solar heat system and ventilation system).

In all, operating savings amount to DKK 32.6 per m^2 and operating costs to DKK 12.1 per m^2, resulting in a total saving on operating costs of DKK 20.5 per m^2 floor space.

The calculation of the present values shows an increase in the life-cycle economy, per m^2 floor space, from DKK 13,256 to DKK 13,591, with an uncertainty of DKK 8 16 and DKK 825, respectively.

In the housing project in question there is thus a small increase in the life-cycle cost. However, special funding has been obtained for the extra investments, which are not incorporated in the program, and that ensures the same life-cycle cost.

Special financing has also been obtained for the extra investments needed in the parallel housing project in Ikast. In this case, however, there is in all a small increase in the life-cycle cost, calculated per m^2, from DKK 13,708 to DKK 14,134. Here, however, the extra investments are deemed to be so valuable for environmental reasons that the project is being built with the calculated life-cycle economy.

It can be added that the construction costs for the said housing projects amount to 60 to 65% of their total cost.

4. Life-cycle economy and environment

In connection with the programming and design of a project, the client, in consultation with the consultants, must consider the environmental aspects of the project. The choice of materials, structures, installations, surfaces, etc. all have consequences for both the life-cycle assessment and the project's sustainability - in other words, its environmental impact.

Some of the consequences will have a direct effect on the project's life-cycle economy. For example, the installation of a solar heat system will necessitate an extra investment and result in a saving in operating costs, both of which can be directly measured in the project's life-cycle economy.

Other consequences are more difficult to measure and will not feature automatically in the life-cycle cost assessment. For example, changing surface treatment, joints and floorings may affect the indoor climate but will not necessarily be reflected in the assessment

A lot of work is going on at present to determine the properties of a building that affect its environmental impacts - the consumption of resources (energy, materials, water and land), the impact on the building's users (working environment and indoor climate), and consequences for the external environment (climatic impact, air and water pollution, and handling of waste).

By using the results of a recently concluded development project "Environmentally managed design", a client and its consultants can systematically map and assess the environmental impacts of a planned project. Through a dialogue, the client must decide on the environmental objectives for the project.

Some of these environmental objectives cannot be translated into a common measure, as kroner and ører in a life-cycle cost assessment. However, it is possible for the client to set up criteria for the various actions that provide a basis for assessment.

To this end, the Danish Building Research Institute (SBI) is working on reference limits for the principal impacts - for example, consumption (of energy, water and materials), acceptable emissions (such as CO_2), measures (for building waste, reuse/recycling and waste water), criteria for indoor climate (measured by humidity, fibres and ventilation), etc.

These reference limits will give clients and their design consultants a better basis for discussing the environmental objectives for the planned project.

Where there are Agenda 21 plans for the local area, they should be included in the evaluation and determination of environmental objectives.

A real comparison between the reference project and the planned project can be obtained by calculating the environmental impacts of both projects. The basis for the comparison is the statement of quantities of materials, consumption on operating items, etc., with assessment of the associated environmental impacts. For the reference project, a greater knowledge is needed of structures, installations, etc. than the aforementioned "normal practice" in connection with the calculation of life-cycle economy.

Lastly, it must be mentioned that the visible operating items in the life-cycle cost assessment provide a natural basis for the preparation of green accounts. These accounts are an aid to continuous collection of data from practice and thus offer a better basis for future life-cycle cost assessments.

As a general rule, it is important to look not only at the life-cycle economy of a project but also at its environmental consequences. An extra investment and higher life-cycle costs may be found acceptable if the environmental benefits achieved are deemed to be higher than the extra investment, as in the case of the above example.

5. Local conditions

The local conditions can have a big effect on the calculation of present values. This applies not so much to the construction costs as to the operating costs relating to the supply of water, heating and electricity and to waste handling.

In other words, the optimum sustainable solutions may vary from place to place.

For example, the heating installation, calculated in present value per dwelling, varies from DKK 132,000 to DKK 158,000, price level January 1994, including 25% VAT. The variation is due to both differences in the technical solution and differences in the "pricing policy" in the area in question. In this case, the use of solar heat will thus not be the best solution from the point of view of life-cycle economy, but may be so from an environmental point of view.

It should also be mentioned that the price with use of district heat can vary by a factor of 4, reflecting the fact that district heat suppliers charge very different prices.

For the drainage installation, the present value per dwelling varies from DKK 59,000 to DKK 109,000. A factor that plays a role here is whether a charge is payable on saved waste water because of percolation of stormwater.

<u>In other words, such factors as connection charges, fixed charges, investment contribution, metered billing, and regular waste-water charge, can affect the calculation of a project's life-cycle economy.</u>

6. Conclusions

For a housing project, the construction costs account for 60-65% of the total life-cycle cost, assuming a lifetime of 30 years. It is therefore not just the construction costs that must be considered when deciding between different solutions, but the entire life-cycle economy.

For the Danish Ministry of Housing and Building, the consulting engineers Birch & Krogboe have designed a large PC program as an aid in the assessment of the life-cycle consequences of different choices during the planning and design of housing projects.

The main features of the program are as follows:

- After some few values concerning supply prices etc. and the size of the planned project have been entered, the program computes the construction costs and the life-cycle economy for a <u>reference project</u>. This project corresponds to normal practice for low-rise and high-rise housing.
- The life-cycle economy of the <u>planned project</u> can then be calculated by changing the data for the reference project where these differ from the planned project.
- The <u>uncertainty</u> in connection with the calculations is given for both the reference project and the planned project. A complete assessment of the proposed solutions in the planned project can thus be carried out. It is important here also to pay attention to architectural and environmental factors.

- The environmental factors must be clarified through a dialogue between the client and its consultants aimed at determining environmental objectives for the project. It is important to note that some of the environmental consequences of different choices will be reflected in the life-cycle economy, while others will not necessarily be reflected in it.
- The local assumptions, especially those concerning supply prices, will vary from place to place. If only the life-cycle economy counts, this means in practice that "pricing policy" may determine the choice of solutions.

The program is a valuable and speedy aid in life-cycle cost assessments. However, the results must be subjected to a critical review in which account is taken of other aspects, such as architectural and environmental factors.

References
(only in Danish)

1. Guide to life-cycle cost assessment in the building industry, Danish National Housing and Building Agency, 1989
2. Description of life-cycle cost assessment as a management tool in the building industry, Danish Association of Consulting Engineers, 1993
3. Report on life-cycle cost assessment, Danish National Housing and Building Agency, 1993
4. Life-cycle cost assessment - as a partial management tool for environmental action, Danish Ministry of Housing and Building, 1994
5. Trambolin - a PC program for life-cycle cost assessment, Birch & Krogboe, 1997.

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Intelligent Environmental Modelling of Building Performance for Sustainable Design

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Abstract
A sustainable approach to building design is now essential. Sustainability emphasises relationships rather than pieces in isolation. By taking a holistic approach and using the interrelationship of the sun, wind and the building's form, layout and orientation a building's design can be optimised to achieve the maximum contribution of natural light, natural ventilation and solar heating. This significantly reduces the requirements for using up fossil fuels, limits carbon dioxide emissions to the atmosphere and contributes to sustainable building design. Intelligent environmental modelling of buildings is required to optimise this design approach. This paper presents new state of the art dynamic simulation software, which allows a range of environmental performance assessments to be carried out on a building's design using one computer model of the building. Simulation results are included for solar analysis, natural ventilation analysis and daylight analysis as well as total energy requirements. Buildings that have been designed using the software have resulted in significant reductions on the impact these buildings have on the environment. A case study building is included as an examplar of this new design. This building is using 81% less energy and producing 64% less CO, than a conventionally designed building.
Keywords: Intelligent environmental modelling, dynamic building simulation software, sustainable design, environmental performance assessment, simulation modelling.

1.0 Introduction

We are becoming more and more aware of the impact that the construction of the built environment is having on the environment. Rogers [1] advises us that mankind's habitat – our cities – is the major destroyer of the ecosystem and the greatest threat to humankind's survival on the planet. Boonstra [2] has found that 50% of the material resources taken from nature are building-related and 40% of the energy consumption in Europe is building-related. Agenda 21 endorsed at the Earth Summit in Rio de Janeiro in 1992 is a major blueprint for how the world's nations can work individually and collectively towards sustainable development for the 21st Century. One of the major aims of Agenda 21 is to reduce the amount of energy and raw materials society consumes. As we attempt to comply with the concepts of sustainable development we need to address very seriously the impact of the construction industry on the global environment and significantly reduce the amount of energy used for our buildings.

Baker [3] investigated the factors upon which the energy performance of non-residential buildings depended and concluded that building design accounted for a factor of 2.5 in their energy consumption and building design and systems together accounted for a factor of 5 in the energy consumption. Better designed buildings and their systems can therefore play a major role in reducing the energy consumed and the impact buildings have on the environment.

In order to evaluate the most significant design parameters accurate information should be available at the early design stage as it is at this stage that the most reduction in environmental impact can be made.

Dynamic building simulation software is now available for use from the early design stage to examine the interrelationship of the building's form, layout and orientation with the sun and wind. In this way a building's design can be optimised to achieve the maximum contribution of natural light, natural ventilation and solar heating.

2.0 Sustainability in our societies

The concept of sustainability has been around for a long time, although only recently has it entered popular culture. The modern roots of sustainability began in the early 20th century theory of renewable resource management, most notably in sustainable agriculture and forestry, and in theories of "sustained yield." However the concept of sustainability has now become the integration of human, social, cultural and economic development previously studied and dealt with separately.

The modern sustainability movement began when The World Commission on Environment and Development, through the Brundtland Commission, released their report "Our Common Future" in 1987. The Brundtland Commission defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The Brundtland report has been reviewed variously as clever green repackaging of the status quo of international trade and finance, or alternately as a sign of hope for the human race. The Bruntland definition of sustainability is widely used and has brought more people into the discussion on what is necessary for sustainable development.

As we find out new information on the damage being done to the Earth's eco-systems and as world population continues to increase different standards may be required for sustainability. Sustainability is thus a complex and evolving issue.

More attention is now being paid on how to produce things with less energy and with less damaging ways of supplying this energy. Information technology is also offering a huge increase in access to knowledge and communication without much expenditure of energy in the equipment itself and reducing the need for transport. This may lead to very different lifestyles in the next century. Building designers need to use the new information available and a new design methodology to produce low environmental impact buildings.

3.0 Simulation modelling

Recently developed state-of-the-art dynamic computer simulation software allows a range of performance assessments to be carried out on a building's design using one computer model of the building. The software is built around the Environmental Systems Performance (ESP) program researched and developed at the University of Strathclyde, Glasgow. ESP has been tested in a number of EU projects. On the basis of these and other findings the ESP program has been declared the European Reference Model for Passive Solar Design.

3.1 Simulation methodology

Zones within a building are defined in terms of geometry, construction and occupant profiles. Zones are then interlocked to form a building and leakage distribution is defined to enable airflow simulation. The plant systems network is then defined (if one exists) by connecting individual components. The multi-zone building and multi-component plant are connected and subjected to simulation processing over a user defined period (from 1 week to 1 year) using hourly values of weather data obtained from the meteorological office.

At the early design stage ESP is particularly powerful since it can be used to quantify the performance impact of the site, the building geometry and construction: all factors which have considerable impact on energy performance and costs. At the more detailed design stage ESP allows the designer to focus on issues of comfort and control.

Other programs in the suite can carry out performance assessments which include daylight analysis, solar energy analysis, natural ventilation analysis, detailed air velocity, temperature and relative humidity analysis, visualisation analysis and CO, SO, and NO, emissions. The use of one computer model of the building for all the performance assessment evaluations means that building geometry need only be input once. Another advantage is that when for example trying to optimise the building's facade design in terms of thermal performance, natural ventilation and daylight, results are analysed based on the same window design, percentage glazing ratio, obstructions from adjacent buildings etc. The model of the building can be easily updated to allow many evaluations of the significant design parameters.

The software provides information for the team (client, project manager, architect, mechanical and electrical engineer structural engineer and quantity surveyor) involved in the design of a building project. The design team members communicate through the Virtual Reality Model of the building. The model of the building is produced by the 4D modelbuilder program -see figure I below. The software can be used to provide the clients design brief and then support the design team from the initial sketch design phase, through detailed design and construction.

3.2 Performance assessment	**simulation program**
• Building Capital Cost Analysis	Ideal
• 3D Visualisation	Rove
• Visual Impact Assessment	Landform
• Detailed Lighting Simulation	Radiance
• Solar Shading Analysis	SunCast
• Bulk Airflow Simulation	MacroFlo
• Microscopic Air Flow Analysis	MicroFlo
• Simulation Results Analysis	XTRA
• Dynamic Thermal Simulation of Building & Plan	ESP
• Costs and Emissions to the Environment	Ergon
• Smoke & Fire Simulation	Jasmine
• Occupant evacuation	Simulex

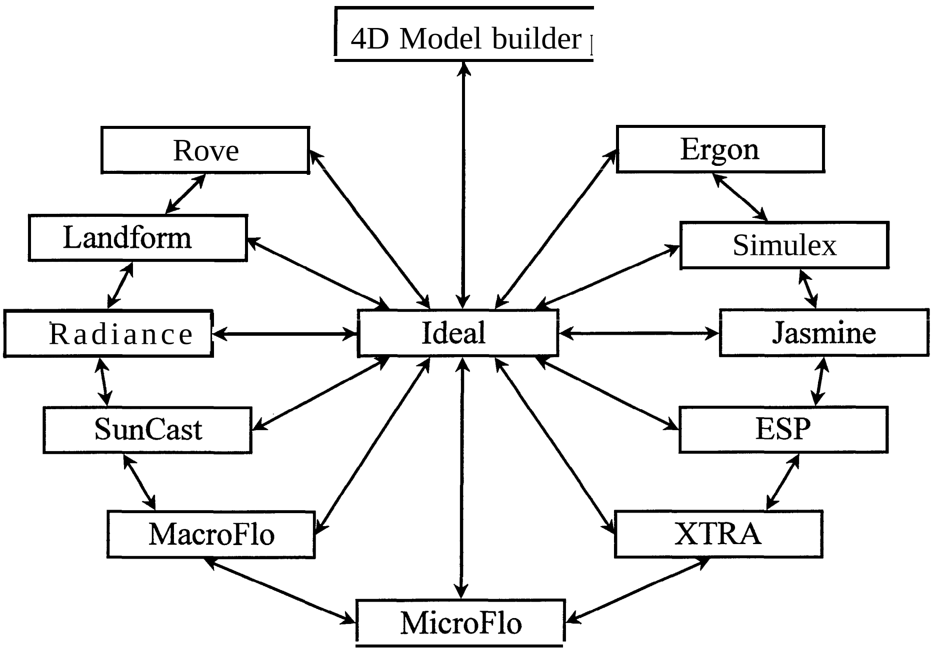

Figure I Performance Assessment Simulation Programs

4.0 Sustainable building design

The criteria for evaluating sustainable building design is being investigated and researched by an increasing number of groups some of which are the Building Services Research and Information Association (BSRIA) in the UK, The Earth Centre at Denaby Main, South Yorkshire UK, as well as CIB. The outcome of this research is eagerly awaited.

In the context of this paper sustainable building design is considered to be the use of the interrelationship of the sun, wind and the building's form and orientation so that the building's design can be optimised to achieve the maximum contribution to natural light, natural ventilation and solar heating This eliminates the requirement of using fossil fuels and carbon dioxide emissions to the atmosphere and contributes to sustainable buildings.

5.0 Building environmental performance optimisation

In order to optimise the building's environmental performance a number of assessments can be carried out using the simulation software. Typical assessments that can be carried out to optimise the design in terms of maximising the contribution of solar energy and daylight and using natural ventilation are explained below.

5.1 Solar analysis

The SUNCAST program is used to evaluate the effect of obstructions on the solar performance of the building model over the year. One example of shading that occurs from adjacent buildings at 16.00 hours is shown in figure II. The hourly values of available solar energy calculated over the year using this program is transferred to the ESP program and the solar energy contribution is subtracted from the heating energy requirements. The parameters that affect the solar performance of the building (e.g. orientation, form, and window design) can be easily changed in the model of the building and the new design evaluated. In this way the solar energy contribution can be maximised. The best position for photo voltaic panels can also be established using SUNCAST. Sustainable design may initially seem suitable only for green-field sites. However the use of this simulation program can increase the possibilities for sustainable design in urban locations.

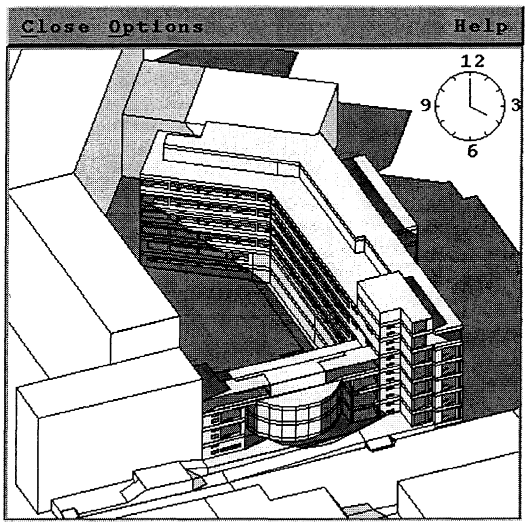

Figure II

5.2 Natural ventilation analysis

The Macroflo program is used to determine the airflow through the building to ensure that the natural ventilation strategy will work. The program calculates the airflow between the zones in the building and outside and takes into consideration the wind speed and direction, the difference in outside and inside temperatures and the stack effect created by the chimney between zones 1 and 9 – see figure III. The effect of louvres and their control on the ventilation requirements can be simulated and checked using the Macroflo program. The building design is also checked to ensure that there are sufficient openings in the correct locations to ensure adequate natural ventilation. To achieve sustainable design means trying out innovative design methods and the simulation software should be used to assess new methods. The Macroflo program is also used to check the layout of the building as the height and position of internal partitions may have an adverse effect on the natural ventilation strategy.

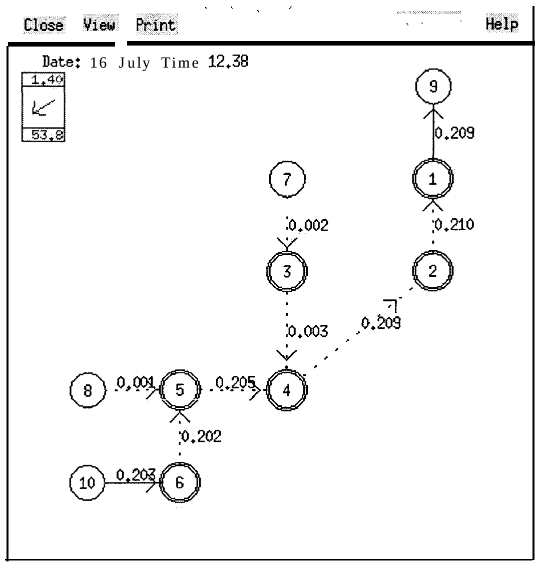

Figure III

5.3 Daylight analysis

The RADIANCE program is used to evaluate the contribution that proper daylight design can be used to reduce the artificial lighting requirements for the building. The generation of electricity can have adverse effects on the environment so maximising the contribution of daylight is very beneficial. Natural light in buildings also has positive effects on the building's occupants. The optimum blade angle for window louvres can be designed and tested. The program can also identify any possible problems arising from glare, see figure IV.

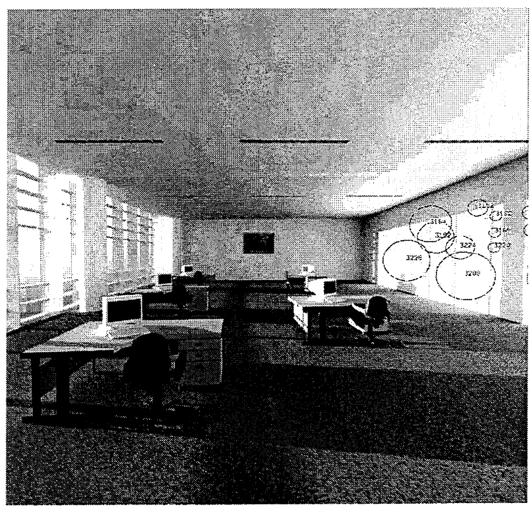

Figure IV

5.4 Orientation and façade glazing ratio

The ESP program considers the interaction of the changing weather conditions and dynamic effect of the building design thus the ability of the building to attenuate external conditions is determined. The ESP program determined both the cooling energy requirements for north, south, east and west orientated zones in summer, see figure V and the heating energy requirements in winter for different facade glazing ratios (i.e. 75%, 50% and 25%) see figure VI. The initial cooling requirements shown in figure V provides the building designer with accurate information on which orientation has the most potential for natural ventilation and also the extent of changes which will be necessary to ensure natural ventilation will work for the high cooling load orientations. The information shown in figure VI allows the building designer to investigate the heating energy requirements in terms of peak load and also energy requirements over the day. The 75% glazing shows the largest peak load but no heating is required between the hours of 12 and 15 due to the solar energy entering the building through the windows and satisfying the heating energy requirements. The 25% glazing has a lower peak load but heating energy must be supplied in the afternoon.

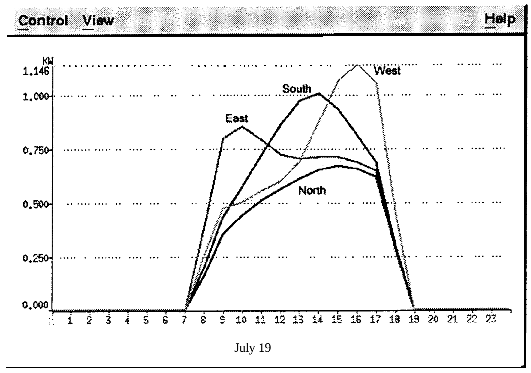

Figure V

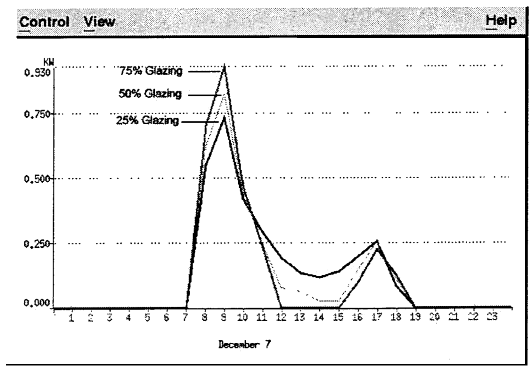

Figure VI

5.5 Total energy requirements

Figure VII shows the total annual energy requirements i.e. the energy required for lighting, cooling and heating. It is only when these three energy requirements have been optimised that the building designer can be satisfied that the building's impact on the environment has been reduced as much as possible.

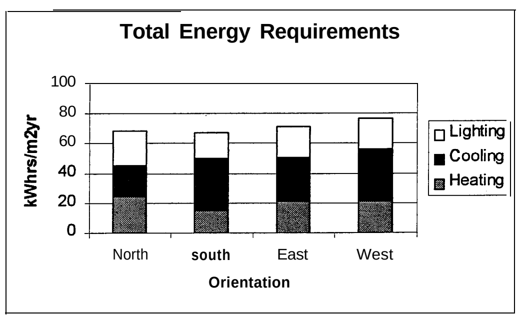

Figure VII

6.0 Green building temple bar

The Green Building in the Temple Bar area of Dublin was designed using the ESP, Macroflo and Radiance programs. The building is now occupied and is using 8 1% less energy and producing 64% less CO, than a conventionally designed building [4]. The ESP program allowed the correct evaluation of the dynamic effect of the building to modify the climate to be carried out, the Macroflo program ensured that the zones in the building could be naturally ventilated from the central atrium when required and the Radiance program was used to design the shape of the atrium and the position of the light-shelves to maximise the contribution of daylight to offset the requirements for artificial lighting. Maximising the building's energy performance and significantly reducing the energy demand meant that solar panels, photo voltaic panels and small wind turbines could provide the basis for a realistic energy system for the building.

7.0 Conclusions

The issue of sustainability will continue to be a problem due to population growth and increased demand for resources and energy. As buildings use up such a large amount of resources and consume so much energy a new design approach is needed. The invention. of electric lighting, central heating, lifts and air conditioning transformed people's expectations of buildings and expanded the range of what was possible in building design. Now there is the requirement for another shift just as radical in kind, in the development of building design for the sustainable environment. It will not be sufficient to take our existing designs and modify them to achieve an improvement in energy demands of say 15% to 20%. The building form, layout and orientation must be analysed using computer modelling to maximise the contribution the sun and wind can provide for heating, lighting and cooling the building. Using this new method the energy requirements and environmental impact of buildings can be significantly reduced. Materials should be selected which have low embodied energy values and whose production should not damage the environment. A great deal can be achieved by intelligent design using this new information but further research is necessary in collaboration with others to maximise this new design approach so that sustainable building design can be achieved.

References

1. Rogers R. Cities for a Small Planet. Faber & Faber Publishers.
2. Boonstra C. Anink D. Handbook of Sustainable Building. James & James Publishers
3. Baker N.V. Energy and Environment in Non-domestic Buildings. Cambridge Architectural Research Ltd.
4. Beattie K. Cooper T. The Green Building Temple Bar. CIBSE International Conference, Eastbourne England

Striving for Harmony between Contemporary Construction and Values of Natural and Cultural Heritage in Protected Areas

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Absract
National and regional parks, natural preserves, landscapes for tourism and outdoor recreation etc., are protected areas. Often in the high density populated Western and Central Europe in these areas is contemporary living process and therefore construction. These are not strict natural reserves. Most of the buildings are residential and recreational.

Therefore the planning of the territory and construction should be in harmony and balance among these 4 interests: 1. Nature protection. 2. Preservation of cultural heritage. 3. Social interests of residents. 4. Holiday. -makers and tourists. Landscape specifics require that the new architecture in such zones would be managed. The main requirements: a) avoid large (high) structures vertically and horizontally; b) avoid locating the buildings on the sea shore or lake shore; c) uphold the visual priority of natural landscape; d) in the building shapes (especially roofs) and materials to consider the local architectural traditions. This example of approach in theory and implementation can be the policy of planning and construction in the Lithuanian southern sea coast, called Neringa (a peninsula of 52 km. Length, consisting of 5 townships - it is the Curonian Spit National Park). The Master Plan was approved in 1970 and 1994.

The variety of local landscape and ethnic traditions is shown in five Lithuanian national parks as well. Each park has his own “spirit”; it cannot be measured, but it must be felt. Architecture should give results that are synthesis of reason and emotion.

Keywords: Architecture, protected landscape, management, national park

Introduction

The most beautiful landscape and landscapes with special importance for science, recreation and tourism are often declared protected areas by law. These can be national or regional parks, or recreational areas of national or international importance. In contrast to American, African and Australian national parks, a rather intensive human activity and noticeable material traces of the post can be observed in national and especially regional parks of Western, Central and Eastern Europe. Buildings, their layout and architecture become here an important component of the landscape. In order not to okstroy the historically formed spacial and social harmony, it is necessary to seek balance among four main interest groups: 1. Nature protection; 2. Preservation of cultural heritage; 3. Social interests of local people and 4. Interests of holidaymakers and tourists. Theoretically, it seems quite obvious, yet in practice complicated and even conflicting situations may arise. Architectural management and some restrictions on building are necessary there.

Building Philosophy

A building is not an end in itself. Its primary goal is social, i. e. man: his life, work and recreation. Therefore, the architecture of a building is not "fine art" is "applied art". Secondly, a building is not "a thing per se" but "a thing in a certain environment". Both above - mentioned aspects are especially important in protected areas, mainly in the areas or recreation. On weekends and during holidays, people have different requirements for the overnight or public service buildings than for those meant for everyday work. These buildings are not goals but means for resting in a beautiful place with a landscape as natural as possible. The landscapes are usually very different. Traditions of social life are also different in different countries, they differ even in distinctive regions of the some country. The primary architectural principle in protected areas, therefore, is variety. No uniform ! The second principle is spacial harmony, not contrast. Architecture in protected areas is not a host but a guest. No matter how much we, architects and engineers, respect our work, it should not conceal the beauty and originality of the surroundings with its size, form and colours. A really professional project will catch the beauty of subtle nuances and harmony. The third principle is regionalism. Even modern architecture . should not be "fashionably cosmopolitan". Cultural peculiarities and evaluation of national identity as well as respect for it become important here. Regional specifics, as reflected in buildings or architecture of whole settlements, are also important as a tourist attraction and, consequently, as a factor in local economy.

Layout of Buildings in a Landscape

In protected areas one can usually find a historically formed network of settlements, villages and separate farms. As a rule, they are also protected and not liable to change. The location of an individual building in a historical village must conform to the tradition. A more complicated case is an intensive

World when hotels and restaurants practically “sit” on dunes and beaches while coastal parks are substituted by’ hoasts of advertisment boards. The famous Miami Beach and Atlantic City in the United States, and Gold Coast in Australia can serve as typical examples. The new continents could have learnt from mistakes of old Europe but they didn’t. Now we, the free Eastern European countries, have a chance in our integration process into the new Europe. This is what we trying to do and will continue doing.

Each sea resort should consist of two parts: day - time resort and night resort. Day - time surroundings should include vegetation, contact with sea and coast, sunshine and peaceful atmosphere. It should be minimally urbanized - small kiosks, pavilions and marinas. Night life emphasizes contacts among people, music and entertainment, discos, etc. Nature is not so important for the “night resort”. It should be, therefore, at least 200-300 metres from the coast. For a lake, the minimal distance is 100450 metres. Hilltops should be treated with caution not only in protected areas but in all recreational areas as well. New buildings should not only be avoided but also for fidden there because a natural silhouette can be easily destroyed, but it is impossible to reestablish it.

The same principles of harmony, variety and synthesis of interests that were mentioned in respect to buildings are also applicable to master plans of recreational areas including both private and municipal land. National and international importance of protected areas and main resorts is superior to private interests of individual persons. A clever person, no doubt, will be able to use these principles for the benefit of his own business.

Relationship between Ethnic and Modern Architecture

The preservation of ethnic architecture in protected areas, and especially in national parks, is obligatory and beyond all dispute. Sometimes the whole settlement or part of it is declared an ethnocultural or urban reserve, for example, the threee villages in the highlands Lithuanian National Park or the historical parks of Nida’s, Preila’s and Juodkrante’s fishermen villages in Neringa in the Curonian Spit National Park. Decayed buildings must be restored. They can serve as dwelling houses or small hotels. Such houses are especially popular among holiday makers. However, while building new hotels, the eternal problem of old and new come to the fore. In Lithuania, we try to keep to the following approach: a) new buildings in protected and recreational areas should not be high or big both vertically and horizontally. The most desirable size is that of a historical building; b) facades may be modern, but the most optimal choice is to use traditional construction and decoration materials; c) traditional roof silhouette is recommended, flat roofs are not built (thought in southern climate such roofs are quite acceptable).

For our general conception the northern, reserved atmosphere of Scandinavia and Finland, with an attempt to avoid cheap effects, is most acceptable. The ideas and works of Alvar Aalto, Ralf Erskin and other colleques are especially close to our understanding.

It is a pitty, but even in the Far East, with its old cultural values and deep

Island can serve as illustrations. The uniform appearance of Hilton, Sheraton and Intercontinental hotels is as irritating as Shell petroleum stations.

The Spirit of National Parks

“Spirit: this concept seems incongruous in the context of congress and serious audience of engineers, isn’t it ? But yes, it does exist; thought it cannot be measured, it can be felt. And architecture should give results that are synthesis of reason and emotion.

There are 30 regional parks and 5 national parks in Lithuania. And each of them, especially the national parks, has its “micro-spirit”. It comprises peculiarities of folk traditions, occupations of the people, nature, and contemporary mode of life. It is difficult to find right words to describe this, but let me try. For example:

The Curonian Spit National Park (Neringa)

Traditional fishing industry and forestry. In comparison with other national parks, the tourism industry is highly developed. The cultural heritage of Lithuania Minor, in particular the remaining timber architecture of Curonians’ villages. Water sports, especially yachting. An excellent sea life museum in Smiltyne. Scientific conferences in winter. Unique dune landscape. The “spirit” of the sea and sand.

The Samogitia National Park

Farming is the traditional occupation. Rich rural and religions architecture. A religions centre in Samogitian Kalvarija. Folk handicraft and folk festivals. A museum of former Russian missile base: The “spirit” of folklore prevails.

The Highlands National Park

More lakes than in other parks. Traditional occupations - farming, fishing and forestry. Old timber architecture villages are unique to this national park. A lake tourism centre. A bee museum. Holiday - making in villages is popular. The “spirit” of lakes and old villages.

The Dzūkija National Park

A landscape of great woods and rivers. The valleys of the Nemunas River and small rivers. Traditional occupation - forestry. The “capital” of mushrooms. The local people are known for their ethnocultural peculiarities and folklore. Historical places Liskiava and Merkine. The “spirit” of huge pine forests.

The Trakai Historical National Park

It is the place of three castles that have historical significance for Lithuania. A unique restored castle - museum on an island. Intensive tourism . The relict Karaim ethnoculture. Festivals of ancient music. Water sports. The “spirit” of old Lithuanian history.

To have a subtle feeling of national parks’ “spirits” is a difficult but obligatory task for designers, architects and engineers. Interesting differences may give new and unexpected ideas that will reveal themselves in the architectural layout of buildings and organization of open spaces.

Experience of the Curonian Spit National Park (Neringa)

It is a long (100 km) Sandy peninsula (52 of which belong to Lithuania) between the Nemunas delta, the Curonian Lagoon and the Baltic Sea. Both the Lithuanian and the Russian parts of the peninsular are national parks. A unique dune landscape (60-65 m high). There are four old fishermen villages in the Lithuanian part: Nida, Preila, Pervalka and Juodkrante as well as Smiltyne weekend recreational area in the very north, near Klaipeda city and port. In 1968-1970 and 1993-1994 master plans and detailed plans for all territory and every village were made for this area. Tourism management and development programme, reglamentation of architecture, nature and cultural heritage protection programme, suggestions for optimal social and development are all meant to preserve and maintain this national park. The population of Neringa is **2,** 6 thousand, in summer they cater for up to 5-6 thousand holiday makers and tourists every day. According to functional and ecological zoning (based on the permissable protective regime), over 66 % of the area are landscape reserves and preserves, about 30 % are recreational areas by the sea and the Curonian Lagoon.

Settlement management as well as building policies seek to implement the philosophy and theoretical principles prepared by the Institute of Architecture and Construction in Kaunas which were presented at the beginning of the article. After World War II, with changes in population and a great influx of holiday makers (esp. from the East), a number of new buildings were built and numerous old houses restored. At present practically no house is higher than three storeys, no ferro- concrete structures were used. The first flat roofs are now being replaced by slanting tile roofs. There are a lot of timber or combined brick and timber facades. One can still feel the "spirit" of the villages of the ancient Curonians. Traditional water occupations and water sports have been preserved.

Yet, there have also been mistakes. The historical hotel "Jurate" in Nida as well as new of "Santauta" and "Azuolynas" hotels in Juodkrante are too big. There is a dangerous tendency towards cosmopolitan commerce felt in the new municipality that organizes "Rock music shows" and motor rally races. Intentions are even voiced to built a new bridge and airport establish the Casino. We are of the opinion that the task of architecture professionals is not only to make a master plan as a guideline for the municipality but also to continue our elucidating and humane mission all the time. The idea of harmony and balance will be crushed if only side of interests will be accentuated. To preserve the uniqueness and "spirit" of the place is important not only for us but also for the whole World. On the threshold of the 21 st century we say: "Let's advance ourselves !"

Conclusions

The tasks of land use and land management in protected areas are much wider than just relations between buildings on the side and nature and cultural values on the other. They have been shortly discussed in the present article. On the whole, it is worthwhile to remember the new definition of architecture adopted by the International Union of Architects (IUA) in Warsaw in 1981 more often. Instead of the old statement: "Architecture is the art of construction "it is said now: “Architecture is the art and science of shaping environment”. A building is just one element of the environment. The responsibility of architects and engineers in creating this element has, therefore, been growing. The 21 st century is the century of sustainable development. The ideas and principles applied at present in protected areas will become more and more useful in all areas as well.

References

1. Stauskas, V. (1997) Recreational Architecture in the recreational landscape - host or guest ? *Proceedings of34 th IFLA World Congress,* vol. 2, Buenos Aires, Argentina, p. 21-27.
2. Stauskas, V. (1996) The strategy of Lithuanian seacoast territorial planning. *Institute fur Ökologische Raumentwicklung (IÖR)*, Schriften, No. 17, Dresden, p. 66-68:
3. Stauskas, V. (1996) The planning of recreational regions in Lithuania. *EKISTICS*, vol. 61, No. 364/36, Athens, Greece, p. 94-99.
4. Stauskas, V. (1992) Relations between cultural heritage and natural values in the National Parks of East Baltic countries. *Proceedings of the 29 th IFLA World* ***Congress,*** Seoul - Muju Resort, Korea, p. 33-35.
5. Stauskas, V. (1974) The ‘principles of architectural and urban planning management in Neringa (Curonian Spit). *Problems of Lithuanian architecture,* vol. 4, Vilnius - Kaunas, p. 28-54 (Lithuanian).
6. The master plan of Curonian Spit National Park (part of architecture and planning).(1994).- *Institute of Architecture and Construction.*- Kaunas, (head of team V. Stauskas). (Lithuanian).

Persistence of Energy Savings of the UK's Energy Efficiency Best Practice Programme for Buildings

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Abstract
The Energy Efficiency Best Practice Programme is the United Kingdom's independent information dissemination programme on energy efficiency and was established in 1989. The programme is jointly managed on behalf of the Department of the Environment, Transport and the Regions (DETR) by the Building Research Energy Conservation Unit (BRECSU) and the Energy Technology Support Unit (ETSU). BRECSU, part of the Building Research Establishment, is responsible for energy efficiency in buildings whilst ETSU is responsible for the programme's industrial processes component. This paper is concerned solely with the buildings element of the programme – referred to as the EEBPP throughout. The aim of the EEBPP is to advance and spread ways of improving the efficiency with which energy is used in UK buildings. Under the programme information on energy use and energy saving measures is gathered and disseminated through publications, workshops and other events. Annual assessment is made of the total energy savings resulting from the programme including, in particular, its influence in each of thirteen building sectors in which the programme is active. To date energy savings have been cumulatively added, year on year. However, now that the programme is relatively mature, it is important to account for any lack of persistence/sustainability of energy savings that may occur in practice. It is generally accepted that the persistence of savings attributed to energy conservation programmes is difficult to monitor and evaluate due to the numerous variables that affect the reliability of savings and the practical challenges to measuring these variables. This paper reviews the international research of persistence of savings in energy conservation programmes and discusses a recent initial study for specific application to the UK's EEBPP. The study resulted in the development of a matrix system of standard persistence factors. These factors relate the frequency of occurrence and the severity of the reduction in persistence. One factor is selected for each measure and for each particular building sector for each year of the EEBPP impact assessment. Although the values are tentative at this stage, due to the lack of research in this field, the study has resulted in a system which can now be applied to the programme's cumulative savings and thus start to take account of persistence effects.
Keywords: Energy efficiency, impact assessment, persistence, sustainability.

1 Background to the study

The Energy Efficiency Best Practice programme for Buildings (EEBPP) is managed by BRECSU (the Building Research Energy Conservation Support Unit) on behalf of the UK's Department of the Environment, Transport and the Regions (DETR). The programme is the UK's largest information dissemination programme for buildings, with an annual budget of around £7M. The programme aims to:

- Generate information on new and proven techniques for reducing energy use in buildings, establishing what represents good practice
- Present information in different forms for different target audiences
- Disseminate guidance to all target groups through documents, seminars, workshops, etc.

In order to measure the effectiveness of the programme in stimulating real energy savings, BRECSU has developed an impact assessment methodology for the programme and undertaken an annual impact assessment survey every year since the programme's inception in 1989. Essentially this establishes what energy saving measures have been installed in buildings in each sector through clear influence of the EEBPP. Results so far estimate the cumulative primary energy savings to the end of 1996/7 at 86PJ/year, compared to the programme's current target of 1 10PJ/year by the end of the year 2000.

In producing cumulative savings, measures installed in a particular year are assumed to continue to deliver the same savings each year thereafter. As the programme matures, it is necessary to recognise that, for many measures, this is an over-optimistic assumption. Savings in fact are likely to reduce over time. This is the concept known as the persistence of energy savings. This paper details the initial study into the issue of persistence and raises questions which are likely to require further investigation.

2 Definitions

One problem is that the term "persistence" gets used in many senses: the whole concept ie the persistence effect; or the attribute of a particular measure. So that when you say 'persistence decays', you are using the term differently to 'persistence is the phenomenon under which energy savings vary over time'. Service life is only one aspect affecting the persistence of energy savings.

2.1 Persistence

As the purpose of this study was to develop a methodology that could allow persistence to be taken into account in the EEBPP's impact assessment analysis, it is essential to be clear on what is meant by the term 'persistence' in the context of this study. For this study 'persistence' means 'sustaining the level of energy savings produced by the energy conservation measures installed as a direct result of the EEBPP, as identified by the programme's annual impact assessment'. Impact Assessment of the EEBPP involves estimating the likely realisable energy saving produced by measures installed as a direct result of the programme. The savings analysis therefore accounts for non-ideal aspects of installation and operation ie that the full technical potential for savings is unlikely to be realised. Persistence issues apply to energy savings produced by the energy conservation measure from the post-installation stage onwards.

For example, lack of persistence includes:

- Known effects of intrinsic deterioration of energy efficiency where this reduces the level of efficiency used for the initial energy saving calculation (eg Argon gas leaking from double glazed units over time)
- Reductions in efficiency due to changes in management, maintenance and use post-installation.

However, persistence does not include:

- Nationally applied changes in the periods and intensity of use of energy saving measures (eg longer opening times) or annual variations in the area of application of the measures (eg different floor area figures due to closing of classrooms or wards) as these are currently taken into account
- Reductions in efficiency due to normal standards of manufacture, design, installation, commissioning, management, maintenance and use (normal standards can be expected to be less than perfect and only normal levels of energy saving will have been taken into account when setting the levels for calculation in the impact assessment)
- Intrinsic deterioration of energy efficiency that is normally allowed for in design calculations (eg gradual light output reduction of fluorescent lamps).

2.2 Service life

The study recorded the service life of measures where the information was available, although this is not the whole picture and only one issue affecting the persistence of energy savings. If an item reaches the end of its service life and is replace by a similar item, the saving of energy will not be affected. The service life does affect the estimates of persistence of energy savings, however, in cases where:

- The item is not replaced at the end of its service life (eg heat recovery wheels)
- The replacement is less efficient (eg ordinary air filled double glazed units replacing argon filled low emissivity glass units)
- The replacement is more efficient (eg new beer chiller systems rather than the recommended old systems currently being installed in many pubs).

3 Practical issues related to persistence of energy savings calculation

3.1 Relevance and availability of data

An accurate measurement of persistence is very difficult. It requires measurements to be made over a long period during which other things, that might upset the measurement, remain static (eg measurement can be upset by different use of spaces, by changes in equipment and security measures or even by growth of sheltering trees). Researchers have generally avoided this area because of the length of time required for research projects; they are wary of the constantly changing conditions and the large number of variables found in practice.

Besides being difficult to measure, there is a positive disincentive to make measurements. Manufacturers and organisations promoting energy saving do not generally want to publicise decay in persistence in products, few developers want to know about the decline in performance to be expected after the building is handed over. The difficulty of carrying out research and some reluctance to investigate persistence have resulted in a lack of data. In many cases this study has had to rely on anecdotal information and assumptions.

3.2 Basis for EEBPP calculation of energy savings

The EEBPP impact assessment for 1996/7 was based on an assessment of savings made in 13 building sectors by **71** energy savings measures recommended by the programme (not all measures apply to all buildings). Every year the survey collects data on the floor areas to which each of the measures has been applied during the past year. The calculation of energy savings is based upon grossing up to the national stock based upon floor areas. The basis for savings calculated from a particular measure may vary from year to year to account for:

- Changes in regulations (only measures above the baseline provided by regulations or 'standard' practice are counted)
- Changes to the floor space within each building category (eg transfer of social to private housing or closure of hospital wards)
- Number of contributing measures (to ensure that added values are reasonable)

In assessing the savings allowance is made for some of the practical issues that, in real life conditions, reduce the theoretical savings that could be achieved. These issues include:

- The finding in previous surveys that not all improvements in energy efficiency result in energy savings (eg occupants preferring the 'comfort' of warmer rooms rather than all the potential fuel savings from energy measures being realised)
- Normal standards of installation and maintenance (recognising that many measures will not be installed and maintained in a way that achieves maximum efficiency)
- Normal standards of use and management (recognising that use and management often fail to optimise the potential savings from measures).

The calculation of persistence must start from where the impact assessment assumptions stop eg if the analysis assumes monthly cleaning of filters in a ventilation system then annual cleaning could make the system less efficient and would represent a lack of persistence. Therefore the assumptions underpinning the energy savings estimates must be recorded.

4 Working method

4.1 General approach

The study had a number of phases:

1. Literature review of published information on the persistence of energy savings
2. Investigation of persistence issues related to the measures included in the EEBPP's impact assessment, including numerous contacts with manufacturers, building professionals and researchers
3. An investigation into the persistence of energy savings in one building category – health care
4. Development of a method to account for the lack of persistence, for application to the EEBPP's impact assessment
5. Extension of the study to suggest how the method should be applied to all EEBPP building categories.

4.2 Study of previous work on persistence

A literature review showed that almost all references to persistence in the use of energy and buildings were from North America and related to electricity supply policies. Enquiries about persistence of energy savings from building research organisation in Scandinavia, Australia and Japan drew a blank. When the study was explained to one set of research staff who were preparing and issuing guidance on energy saving, said "well, we wouldn't want to know about that – it would threaten our funding". Subjects related to persistence, such as deterioration in thermal performance, were available from some sources in the UK and abroad.

In the UK the Chartered Institution of Building Services Engineers (CIBSE) has embarked on the updating of its 10-40 year old figures for service life. Reliable data in life expectancies are seen as important supporting information in demonstrating the feasibility of a project and potential cost savings.

4.3 Gathering information on measures

In addition to consulting EEBPP publications and others giving guidance and experience on measures, information was gathered from researchers, managers, manufacturers and others on the practical issues related to testing, installing and operating measures.

4.4 Investigation of persistence in health care buildings

In order to develop a methodology for assessing persistence, one building sector was initially chosen for detailed investigation – NHS-Trust buildings. The study involved:

- A study of the EEBPP package of Good Practice Case Studies and Guides on health care buildings and other relevant published material
- Consultation with the EEBPP health care manager, with the Department of Health and with several consultants working in the health care category
- Consultation with seven NHS Trust energy managers.

The aims were to:

- Find whether the managers had evidence of lack of persistence
- Seek reaction to suggested persistence factors relevant to health care
- Gather information on energy management
- Discover the place and status of energy saving within the sector

4.5 Development of a method to account for lack of persistence

A method was chosen that would provide a means to account for the lack of persistence that could take account of whatever data was available without suggesting unrealistic precision. The method would then allow adjustment of impact assessment savings for previous years, whilst allowing the basis for these adjustments to be seen and for changes to be made as additional data becomes available.

4.6 Extension of the study to all building categories

Following development of a methodology for health care buildings, it was widened to incorporate all 13 building categories and developed in order to provide decay factors for a period of 15 years.

5 Findings related to measures

5.1 Persistence of measures generally

No regular pattern of persistence decay was found – each measure must be considered on its own and often in the context of different building categories. Decay does not occur regularly over time. It may be more rapid at first or speed up towards the end of service life, as happens with swimming pool covers. Commonly, however, decay affects measures at a particular time eg when a building is refurbished or when an energy manager is removed.

5.2 Changing views on persistence in North America

There is a wealth of American material on this subject, which cannot be adequately covered in a few paragraphs. However, a 1992 paper by Edward Vine [1] provides a good starting point. It presents a conceptual framework for analysing persistence of energy savings, summarises the limited experience of what was known, and provides guidance for retrospective and prospective studies, suggesting strategies for both conducting research and developing policies and mechanisms to help ensure the persistence of savings.

In American studies, persistence has a wider meaning than in this study, because the North Americans have been concerned with energy saving programmes where approvals are sought at the design stage and lack of persistence can also occur between the initial approval of a proposal for saving energy and what is actually installed, while this study only looks at persistence in relation to installed measures.

Throughout the 1980s, persistence of energy and demand savings became important to many stakeholders. Resource planners needed to know if the energy saved through energy efficiency programmes was off-setting generating resources. Utility shareholders needed to know if financial incentives based on measured energy savings were continuing. At the time of the Vine paper, persistence of energy savings was probably the single largest, unanswered question in the consideration of 'Demand Side Management'. It was assumed to be relatively constant and most analyses of persistence relied on engineering estimates of measure life. The limited empirical research, at this date, raised questions about the validity of using manufacturer's claims for physical measure lives. To answer the above questions and concerns, researchers have focussed on: exploring evaluation techniques, gathering case data, teasing out relevant influences on persistence, and developing realistic models for everyday use.

The introduction of competition in the USA has shifted areas of interest to parallel those in the UK. International accords such as that at Rio have heightened the importance of being able to accurately include the persistence of energy measures contributing to national CO_2 reduction programmes. Vine identified two dimensions of persistence, which most subsequent papers have taken up: Measure lifetime and operation, and total and net Programme energy and peak demand impacts. These are inter-related in that Programme persistence includes Measure persistence, as well as other factors. This paper was valuable in ascribing equal importance to technology and behaviour. They both affect persistence, they often interact, and they are difficult to separate, particularly behaviourally – dependent measures such as cleaning refrigerator coils and resetting HVAC time clocks, to accommodate occasional unplanned occupancies. As the field has been explored in greater depth so the ideas that simple solutions would be found have receded. For instance, reasons for a lack of persistence were cited by Hicks [2] as not solely about measure failure but related to market factors – remodelling cycles, operational factors and technical degradation.

6 The results of the UK study

6.1 Application of persistence factors to building categories generally

The persistence of measures will vary between building categories. For example, when compact fluorescent lamps are used within housing it is estimated that a large proportion of them will be replaced with tungsten lamps (this is supported by retail sales figures and is probably due to unfavourable customer reaction to the appearance and the-delayed start up of energy efficient lamps). Building categories vary- in three respects:

1. Their construction; eg categories such as offices, with fully glazed facades have more need of shading and cooling than new housing
2. Their management; eg buildings with sophisticated equipment and control systems require management that is capable of optimising their operation
3. The way they are used; eg measures installed in buildings that are in continuous use can produced greater savings than in buildings of the same floor area that are only used occasionally.

Each of these variables must be taken into account when assessing persistence factors for both new and existing buildings.

For some measures refurbishment or change of use is likely to affect persistence because the measures may be removed or made less effective by alteration work or change of usage (eg heating zone controls when the building is differently subdivided, point of use water heaters when sanitary facilities are rearranged, or energy policy when a new firm takes control of the building). It follows that the shorter the period to refurbishment in a particular building category, the greater the likelihood that persistence will decay. In the UK approximately 4% of the total building stock is refurbished each year, although there is a wide variation in the periods of refurbishment even within the same building category.

6.2 Application to health care and other building sectors

Details of application of the methodology to the Health Care sector will be presented at the conference. There is not space for a detailed summary here. However, detailed investigation of and consultation with representatives within this sector enabled a matrix system of standard persistence factors to be developed. These -factors relate the frequency of occurrence of decay in energy saving over time and the severity of the reduction in persistence. One factor is selected for each measure and for each building sector for each year of the EEBPP impact assessment, making 887 persistence factors for 1996/7 alone. These factors have been developed for a period of 15 years, allowing retrospective application to the EEBPP and some forward application in years to come.

7 Conclusions

This study has developed a systematic means of accounting for any potential lack of persistence of EEBPP savings for all 13 building sectors promoted by the programme. The factors consider energy savings post-installation. Therefore future impact assessment of the EEBPP will include the following persistence methodology:

1. A base figure of the energy expected to be used in a typical building of a particular category
2. The potential savings that could be expected from the introduction of measures under ideal conditions

3. The saving that is likely to be achieved in real conditions (based upon 2 but taking account of design, installation, maintenance and use)
4. The annual savings that can be expected when factors related to changes in savings over time are included (including deterioration of products, downgrading of management staff and different uses for part of a building)

We are some way towards this ultimate system, but it must be noted that the lack of data on performance of energy measures over time means that the persistence factors can only be tentative without more research. Nevertheless, we have developed a system which can now be applied to the programme's cumulative savings and start to take account of persistence effects.

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References

1. Vine, E.I. (1992) Persistence of energy savings: what do we know and how can it be measured?, *Energy* Vol. 17, No. 11, pp. 1073-1084.
2. Hicks, E.G. (1994) Emerging Issues in Evaluation, *Building Tomorrow: the Path to* Energy *Efficiency*, Conference Proceedings.

An environmental perspective on UK construction materials

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Abstract
The environmental effects of UK construction and construction materials are reviewed in an attempt to assess their importance for research, development and UK sustainability. Usage of construction materials, floor areas, energy use and emissions to air are examined but many assumptions are necessary to extract construction-related components from national environmental statistics. It is shown that in-use and transport contributions from construction are major components of national impacts, particularly with regard to energy use for thermal comfort in buildings and the transport between buildings of people and goods. In relation to the cumulative, long-term influences of urban planning and transport, energy efficiency associated with building design, durability and reuse of buildings, the direct role of materials manufacture is currently of lesser significance. It is concluded that an improved assessment of sustainability for construction and construction materials requires research to determine a set of environmental indicators for construction and analysis methods wherein technical results can be transparently evaluated from a representative range of alternative viewpoints. Research on construction materials should be aimed at facilitating the life-cycle analysis of environmental impacts over the design, supply, construction, use, refurbishment, repair and disposal stages of the life cycles of alternative structures so that the best practicable options can be determined for a specific suite of environmental issues. The software tools and databases should permit incorporation of life-cycle analyses into routine construction planning and design. With regard to the sustainability of the UK's energy consumption, future environmental research should examine and stimulate the integration of construction with the provision and use of renewable energy.
Keywords: Buildings, construction materials, emissions to air, energy, indicators of sustainability, transport.

1 Introduction

This paper introduces some general environmental issues for construction, outlines policies, summarises construction materials usage and environmental effects and provides an environmental perspective for construction materials in relation to other construction sectors, UK environmental performance and research strategy. It is emphasised that many assumptions were needed to extract construction-related components from national statistics [1-7]. The **costs** associated with the control of environmental impacts and the **value** of the corresponding environmental improvements are important issues for a sustainable strategy but they are not addressed; the analysis tools are still being developed and information is sparse. A recent European Community proposal aims to accelerate its sustainability programme by actions relating to climate change, ozone depletion, acidification, waste, noise, transport and energy and other organisations also highlighted these issues [1-7]. Sectors such as building owners, building users, designers, builders, educators, investors, insurers, lawyers, environmental pressure groups and the public can have additional environmental concerns [1].

The incorporation of a formal environmental component into construction design is becoming increasingly necessary and should be based upon a holistic life-cycle analysis to determine the best practicable environmental option wherein the designer identifies those materials and components that most effectively complement his designs. Design tools should not require over-simplistic, preliminary environmental screening of materials; this could restrict the development of some effective and innovative design options. The location of a structure relative to the sources of materials and components from which it is built will influence environmental burdens arising during early life-cycle stages. More importantly its location relative to those of its users and suppliers will influence the burdens accumulated over the lifetime of a building. The effects of heating, cooling and ventilation also accumulate over the lifetime of a building to constitute a major component of its environmental impact. All of these impacts should thus be analysed in an environmental component of design.

Within a given set of environmental analysis boundaries there is a range of possible analysis conventions and assumptions; the current state-of-art is insufficiently advanced for general agreement although IS0 is currently attempting to develop preliminary LCA standards. Alternative sets of conventions and assumptions for a specific building could lead to significantly different outcomes from environmental analyses (even though the actual environmental impacts remain fixed). Sensitivity analyses are needed to demonstrate the influence of the alternative analysis conventions advocated by different sectors and thus promote constructive debate. UK government departments have recently initiated the development of environmental satellite accounting to link market activities with their impacts upon the use of natural resources, degradation of the environment and the cost of activities designed to mitigate these impacts [3]. Pilot studies [8] examined atmospheric emissions, along with economic indicators, categorised by industry, fuel and transport mode; mitigation expenditure was about 0.6% of sales.

2 Construction materials

This section briefly indicates the quantities of materials used in UK construction, the energy associated with their manufacture and the associated emissions to air. Diverse source of UK data were reviewed to compile Table 1, [1] so only broad conclusions can be drawn. The data include transport to the UK; transport within the UK is covered separately. It was found that no single material was dominant with regard to energy use; indeed the initial six groups of materials each contribute between 7 and 18% of the construction materials total. The remaining group (gypsum products, glass, asphalt, mineral insulation, plastics, paints, adhesives and sealants) account for 24% of the construction materials total. Construction materials are used in substantial quantities (291 Mt) but 'the associated energy constitutes only 6.1% of the total UK delivered energy [1,2]. If allowance is made for differences in populations the total quantity of construction materials used in the UK appears to be virtually the same as that used in Denmark [1].

The emissions to air associated with the manufacture of construction materials range from 4 to 13% of UK releases and are significant enough that they should be included in assessments of UK sustainability. Information on fine particulate and heavy metal emissions were limited although they may prove to be critical for the construction materials industries. The major portion of emissions shown in Table 1 derive from the initial six groups of materials; this is due to the large quantities that are used. The first five tabulated material groups are closely connected with mineral extraction; however, the bulk of raw materials extracted in the UK are geologically abundant and involve only limited transport burdens. A qualitative assessment [1] suggested that the following parameters were also of environmental significance for construction materials: material depletion, manufacturing wastes, transport impacts, land use, heavy metals, chlorides, fluorides, VOCs and land pollution.

Materials	Carbon dioxide (Mt)	sulphur dioxide (kt)	Nitrogen oxides (kt)	VOCs (kt)	Carbon monoxide (kt)	PM10 (kt)	Delivered energy (PJ)
Aggregate/stone	3.85	15.66	64.2	18.7	37.5	?	41.8
Portland cement	10.14	18.50	31.2	0.5	9.5	3.2	58.6
Clay bricks	3.10	7.90	6.1	2.6	9.4	0.5	29.4
Ferrous metals	7.65	51.87	34.0	10.2	445.7	2.4	69.5
Non-ferr. metals	2.04	15.53	8.4	9.4	20.3	>0.4	27.1
Timber/panels	6.56	19.68	65.6	32.8	98.4	?	65.5
Other materials	3.80	21.86	21.1	19.3	8.5	>4.6	94.3
Total	37.14	151.0	230.6	93.5	629.3	>11.1	386.2
(% of UK)	(6.8)	(5.6)	(10.4)	(4.2)	(13.0)	(>4.4)	(6.1)

Table 1 Materials inventories per year for UK construction

3 Environmental significance of structures

This section illustrates energy usage and other environmental effects of structures during their operational period and compares these with the effects arising from construction materials. The energy use for the construction phase is about 54 PJ/year [1]; those for the demolition and disposal life cycle stages are thought to be smaller and are not considered further. The range of structures considered is intentionally broad in order to ensure that construction factors which afford the greatest control of environmental impacts are identified. The energy data in Table 2 are from a wide range of sources [1] and should be regarded as approximate.

There are about 21 million properties in England and Wales so the provision and use of buildings were expected to be major contributors to national environmental impacts. Transport structures such as roads, rail track and bridges, together with passenger and freight requirements are associated with an increasing, transport-related environmental burden. Over the last 20 years there has been an increase of about 50% in fuel usage for passenger and freight road transport [2]: apart from traffic congestion and consumption of petroleum fuel there is an associated burden on urban air quality due to vehicle emissions. The energy consumptions of the passenger and freight transport sectors in 1994 were about 1173 and 503 PJ, respectively [2]. The planning, location, design, construction and operation of transport structures offer an element of control over such environmental burdens.

Most electricity in the UK is currently generated by burning fossil fuels [2]. The recent shift from coal to natural gas burning has reduced polluting emissions to air. The main technologies for renewable energy are wind, waste combustion, hydro-electric, wood fuel, anaerobic digestion, landfill gas and solar [4]. Wind, hydro-electric, wood fuel and landfill gas technologies use substantial areas of land or water and this could limit their application. Indeed there are few remaining sites that are suitable for hydro-electris schemes, which account for 92% of renewable energy in Europe. Biomass and wind-power have increased in recent years and account for about 7% of UK renewable energy. Construction schemes that generate energy from tidal and wave movements have been advocated when there is a parallel construction need for protection against coastal erosion but such energy appears to be significantly more expensive than that generated using conventional methods. Generation of electricity from photo-voltaic panels is

Indicator	UK Total	Construc. materials	Construc. process	Buildings in use	Dwellings in use	Transport	Other sources
Final energy, PJ (%)	6283 (100)	386 (6.1)	54 (0.9)	952 (15.2)	1839 (29.2)	1676 (26.7)	1376 (21.9)
Carbon dioxide, Mt (%)	548 (100)	37 (6.8)	4 (0.8)	77 (14.1)	149 (27.1)	145 (26.4)	136 (24.8)
Sulphur dioxide, kt (%)	2718 (100)	151 (5.6)	21 (0.8)	372 (13.7)	719 (26.4)	251 (9.2)	1204 (44.3)
Nitrogen oxides, kt (%)	2218 (100)	231 (10.4)	8 (0.4)	134 (6.0)	259 (11.7)	1356 (61.1)	230 (10.4)
VOCs, kt (%)	2220 (100)	94 (4.2)	36 (1.6)	27 (1.2)	53 (2.4)	938 (42.3)	1072 (48.3)
Carbon monoxide, kt (%)	4833 (100)	629 (13.0)	3 (0.1)	54 (1.1)	281 (5.8)	3786 (78.3)	80 (1.7)
PM10, kt (%)	250.0 (100)	26.1 (10.4)	4.1 (1.6)	14.5 (5.8)	28.0 (11.2)	71.0 (28.4)	106.4 (42.6)
Heavy metals, kt (%)	4.099 (100)	0.689 (16.8)	0.007 (0.2)	0.120 (2.9)	0.231 (5.6)	0.245 (6.0)	2.808 (68.5)

Table 2 Selected environmental indicators and construction-related contributions

minimal at present but its use in connection with the cladding of buildings and transport structures seems likely to increase [1]. There is much scope for combining renewable energy generation and construction schemes and this would help to raise the 0.5% renewable component of UK energy towards the 5% European figure. There are a several points that emerge from the energy data in Table 2:

1 - energy associated with the provision and use of structures and buildings accounts for about 77% of UK final energy: excluding transport the figure becomes 51%.

2 - energy associated with construction materials accounts for about 7.9% of the construction energy (provision plus operation): excluding transport the figure becomes 11.9%.

3 - improved construction planning and design could substantially influence material, operational and transport energy use and, by implication, UK environmental performance. Provision and use of housing plus transport account for about 60% of UK final energy and should be primary research targets.

4 - an analysis of construction materials usage by type of structure would help manufacturers to anticipate the implications of increasing environmental stringency in specific construction sectors.

Much UK energy use arises from the operation of, and the transport of people and goods between, buildings. An element of control is exercised via planning requirements relating to new housing but, in spite of more onerous thermal efficiency requirements, UK domestic energy consumption has not greatly diminished. Possible additional methods of mitigation are: encouraging refurbishment of existing dwellings and other buildings to improve thermal efficiency, stimulating mixed building redevelopment to reduce travel and setting rebuilding targets to reduce the energy consumption of the UK construction stock. Energy self-sufficiency does not seem beyond current technology, although it is difficult to justify with current economic reasoning. Unfortunately methods and tools do not yet exist for a wide-ranging best-option analysis of the interacting environmental effects arising from housing, buildings, industrial processes and the transport of people and goods.

Table 2 includes emissions that relate to the greenhouse effect, acidification and air quality. The selection of indicators was partly influenced by the availability of data and, in developing an environmental research strategy for construction and construction materials, it would be desirable to examine additional factors, including those from recent UK listings [2]. The UK's Foresight Construction Panel is currently canvassing views on a set of key sustainability indicators for buildings; it has yet to consider civil engineering structures, renewable energy structures, transport or urban planning. UK and international air emissions data [5,6] were used to assess construction-related contributions to emissions of carbon dioxide, sulphur dioxide, nitrogen oxides, volatile organic compounds (VOCs), carbon monoxide, PM,, particulates, and heavy metals.

The total UK carbon dioxide emission for 1994 was 548 million tonnes; the portions attributed to domestic and transport sources were 149 and 145 Mt [1,5]. The portions attributed to buildings in use and the construction process were estimated from the domestic source, adjusted for relative energy uses. The carbon dioxide emissions for construction materials and other UK sources were estimated from the UK total minus those from domestic and other buildings, the construction process and transport; this residue was allocated in proportion to energy use with the proportionality constant being process-dependent [5]. A better approach would be to assess emissions based upon measurements for construction material processes but such data are not currently available. The carbon dioxide emissions from construction materials corresponds to about 7% of the UK total, whereas those from dwellings and buildings amount to 41%.

The emissions in Table 2 for sulphur dioxide, nitrogen oxides, volatile organic compounds (VOCs), carbon monoxide, PM,, particulates, and heavy metals were estimated using an approach similar to that adopted for carbon dioxide. The differences of their distribution between sectors for the various environmental indicators arises from the differing characteristics of transport, process and fuel use. The energy and carbon dioxide data in Table 2 were discussed in May 1997 with researchers from Finland, Denmark, Netherlands, and France [1]; there was fair agreement between countries regarding the portions of national energy use and carbon dioxide emissions attributable to different sectors; construction materials - 5 to 7%, buildings in use - 40 to 50% and transport - about 25%. However, parallel data on other environmental parameters, such as sulphur dioxide, nitrogen oxides or VOCs, were not available for comparison.

The estimates in Table 2 are shown in brackets as percentages of UK totals. Energy approximatelv reflects carbon dioxide emissions but it would slightly over-estimate the national influence of construction materials for sulphur dioxide and VOC emissions and under-estimate their influence for nitrogen oxide, PM,,, heavy metal and carbon monoxide emissions. With regard to buildings and dwellings in-use energy approximately reflects national carbon dioxide and sulphur dioxide emissions but it would over-estimate their effects for other emissions. Even within the sectors buildings in use, dwellings in use, construction process and construction materials energy did not appear to be a reliable proxy for other environmental indicators. It can be argued that construction design and planning significantly influence transport emissions as well as those deriving from dwellings in use, buildings in use, construction process and construction materials. Since the individual emissions from these sectors, with the exception of heavy metals, constitute 52 to 98% of UK totals it is evident that construction research should, with some urgency, explore how design and planning might contribute to improving the UK's environmental performance and sustainability.

It is evident that factors such as initial design, in-use operation, building location, durability of the building and refurbishment strategy are likely to impose larger environmental effects than the particular construction materials selected for construction. However there is a shortage of case studies for different types of construction from which firm conclusions can be drawn. Ideally case studies would quantify environmental effects at each life cycle stage, from materials extraction through building operation to recycling; they would also include sensitivity analyses relating to assumptions. Such case studies would help clarify research directions and would indicate proportionate levels of research and development support that could be expected from different sectors of the construction industry.

4 Concluding remarks

The environmental effects of UK construction and construction materials have been reviewed in an attempt to assess their importance for research, development and sustainability. Many assumptions were necessary to extract construction-related components from National environmental statistics. In-use and transport contributions from buildings and structures are major components of national environmental impacts, particularly with regard to energy use for thermal comfort in buildings and the transport between buildings of people and goods. In relation to the cumulative long-term influences of urban planning and transport, energy efficiency associated with building design, durability and reuse of buildings, the direct role of materials manufacture iscurrently of lesser significance. However the balance may shift if environmental impacts become more heavily penalised, the energy efficiency of buildings improves and construction projects incorporate renewable energy generation. This assessment of the importance of construction is echoed in reports from Building Materials Producers, the Construction Industry Council, the Foresight Construction Panel and others [1].

Research is required to develop a set of construction indicators (environmental, social and economic) and analysis methods wherein technical results, of high integrity, can be transparently evaluated from a representative range of alternative viewpoints so that the roles of construction and construction materials in UK sustainability can be more accurately assessed. Research on construction materials should be aimed at facilitating the life-cycle analysis of environmental impacts of buildings and structures over the procurement, design, supply, construction, use, refurbishment, repair and disposal stages of the life cycles of alternative structures so that the best practicable options can be determined for a specific suite of environmental issues; such holistic tools would obviate the need for over-simplistic, preliminary screening of materials. The software tools and input databases should permit incorporation of life-cycle analyses into routine construction planning and design.

Environmental research should examine and stimulate the integration of construction with the provision and use of renewable energy; this would also create market opportunities for associated technology, plant, consultancy and construction management. Energy use did not appear to be a direct proxy for other environmental impacts such as sulphur dioxide, nitrogen oxides, carbon monoxide, fine particulates and heavy metals. The selection of boundaries and conventions for analyses can significantly affect the outcome and, until better understood, they should be the subject of sensitivity analyses. The environmental outputs from initial research and from subsequent analyses of buildings and structures should be formulated as inputs to national environmental statistics and accounts: they should also be compared with current typical and good practice benchmarks to stimulate improvement.

The benefits of the proposed, broad research and development strategy would be felt at several levels: the effects of construction and construction materials upon UK environmental accounts would become clearer and more amenable to control. It would also provide a framework within which adjustments to the extent and balance of regulation could be assessed for their likely influence upon UK environmental performance and sustainability, an improved perspective on the relative influence of the construction materials sector would highlight critical subject areas, suggest performance benchmarks and indicate an appropriate level of contribution to environmental research. Furthermore there would be encouragement to make more accessible the existing environmental information that has been collected for regulation of pollution and the construction industry would gain additional support from the public and environmental activists, if seen to be promoting improved environmental design and sustainability via appropriate enabling research.

It can be argued that the barriers to the quantitative evaluation of environmental impacts in construction design are so large that a consensus cannot be reached. However the trends within UK Government departments and in other European countries are towards a satellite environmental accounting system in which the environmental impacts are expressed in appropriate physical units and are evaluated using currently appropriate weighting systems [1]. Such an approach enables environmental issues to be given due consideration in assessments of sustainability while allowing alternative evaluation philosophies to be transparently illustrated. Public and government opinion will soon demand environmental assessment in construction: the industry, including its institutions and standards organisations, should participate in and shape development rather than await or oppose it. National statistics are needed on the usage of construction materials and the stocks and energy performance of buildings and structures. These data are essential for setting benchmarks for the environmental performance of construction materials, components, buildings and structures. Where recent data are commercially sensitive then results from a previous year would probably suffice. Environmental standards tend to improve so there would be an inbuilt incentive to supply the most recent data that is consistent with commercial interests.

5 References

1 L. Parrott, Evironmental issues for construction materials research, Department of Environment, Transport and Regions/BCA Report, August 1997, 55pp.

2 Department of the Environment, Indicators of sustainable development for the United Kingdom, HMSO Government Statistical Service, March 1996, 196pp.

3 Statistics Users Council, Proceedings of Conference on Environmental Statistics, Royal Society 19 November 1996, Published by IMAC, 265pp.

4 Department of the Environment, Planning policy guidance: renewable energy (including October 1994 Annex), DOE PPG 22, February 1993, 7pp & Annexes.

5 A. Salway, H. Eggleton, J. Goodwin and T. Murrells, UK emissions of air pollutants 1970-1994, AEA Technology Report, November 1996, ISBN 0705817334, 57pp.

6 G. McInnes, European Environment Agency, EMEP/CORINAIR Atmospheric emission inventory guidebook, European Environment Agency, February 1996, two volumes.

7 Department of the Environment, Digest of environmental statistics, No. 17 1995, HMSO Government Statistical Service, 213pp.

8 P. Vaze & S. Balchin, The pilot UK environmental accounts, Environment Business, 11 Septeber 1996, 1-2.

The Limits to Sustainability

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Abstract
The many worldwide sustainability efforts and movements allude to two distinct but potentially conflicting goals: (1) leaving adequate resources and environmental quality for future generations, and (2) providing for developing countries to create healthy economies that allow their populations to experience a quality of life better than mere survival. Without rapid, dramatic increases in resource efficiency, huge reductions in waste and pollution production, stabilization of population, international accords that limit the production of greenhouse gases, and widespread protection of natural areas for their function and biodiversity, sustainable development will be nothing more than a grand illusion. This paper examines these issues and provides some conclusions about sustainable development in general and, more specifically, about the impacts on the built environment.
Keywords: Sustainable Development, Ecosystems, Resource Efficiency

1 Introduction

The concept of sustainable development is much in vogue and appears in the construction disciplines in various guises such as sustainable construction, ecologically sustainable development (ESD), green building, sustainable architecture, and resource efficient construction. The motivation for these activities is to reduce resource consumption and waste and protect the function and biodiversity of natural systems. The desired outcomes are societies that consume energy, water, and materials at a replenishable rate that can be maintained indefinitely while insuring that natural systems are protected and healthy human habitats are created. The widespread implementation of the reduce-reuse-recycle philosophy and other pillars of this concept is implicitly and explicitly advertised to make the earth's finite quantity of materials virtually inexhaustible. Issues such as population growth, quality of life, and standard of living are tacitly assumed to be accounted for, and addressed within, the framework of sustainability. The reality is that sustainability is constrained by the laws of nature, including thermodynamics, chemistry, time, and perhaps the underlying chaos present in nature. The high degree of self-organization in nature was powered by the availability of solar energy, allowing the complexity found in natural systems to develop. Similarly, the complexity of manmade systems is permitted by the consumption of large quantities of high quality energy that ultimately finds its way, via inefficiency and natural limitations, to low temperature, largely useless thermal sinks. Sustainable development is a highly complex issue with a significant moral component: the current generation must pass on its inheritance of natural wealth, not unchanged, but undiminished in potential to support future generations [1]. Many of the problems encountered as the movement to sustainable behavior is explored have technical solutions but technical solutions are not always possible [2]. People and institutions often have to intervene where pure market forces are unable to correct the behavior of economies that tend to deplete and destroy natural systems.

2 Framing the Debate

There are several sides to the argument about whether humans can continue to increase both their population and aggregate consumption at present rates. At one extreme, the *anthropocentric view,* are those who believe human ingenuity can always develop materials, processes, or systems to compensate for depleted natural resources and damaged ecosystems. The other extreme, the *gaia view,* holds that the earth is itself a living system, that by destroying this system by land development, extractive industries, polluting transport and industry, throwaway attitudes, and a general disregard for nature, mankind is compromising its very existence [3]. It is likely that both of these polar opposites exist simultaneously, not unlike the dual wave-particle behavior of photons. Nature is being ravaged by mankind, the survival of many species is in question, rainforests and fisheries worldwide are being destroyed at an accelerating rate, and the atmospheric concentrations of greenhouse gases continue to rise at an increasing pace. At the same time mankind has proven to be clever and adaptable, with an incredible array of technologies being developed at an ever increasing rate, materials use per capita actually dropping in industrialized countries, and a significant swing in attitude and consciousness toward environmental friendly behavior occurring worldwide. Knowledge can increase the efficiency of natural resource use [4]. However, in spite of mankind's knowledge, four major classes of human activity are rapidly destroying the environment and ultimately mankind's life support system: (1) the alteration of planetary ecosystems, (2) the depletion of nonrenewable resources, (3) the unsustainable use of renewable resources, and (4) the pollution of earth, land, and water systems.

3 Alteration of Planetary Systems

The earth's total surface area of 510 million km^2 consists of a terrestrial component of 147 million km^2 and an aquatic component of 363 million km^2. The Net Photosynthetic Production (NPP) of the terrestrial area is 132.1 billion metric tons (MT) and is estimated to be 92.4 billion MT for the aquatic component. Humans are coopting almost 40% of terrestrial NPP and almost 30% of aquatic NPP [5]. It is likely that the coopting of NPP is proportional to population and a doubling of world population from 1986 to 2026 (5 billion to 10 billion) will result in 80% of terrestrial and 60% of aquatic NPP being coopted. Although the exact consequences of this doubling is unknown, it is probable that the effects will be devastating for global ecosystems. It is unknown at what level of stress these natural life support systems simply collapse to a level where human life itself is threatened. For example, in 1997 fisheries in most oceans around the world are in crisis as numerous species are being severely depleted in an unsustainable fashion that is likely to lead to their extinction. The bottom line is that the co-option, destruction, and diversion of terrestrial and aquatic resources by humankind is contributing to rapid and widespread extinction of species and genetically distinct populations, and the genetic impoverishment of the survivors.

Humans are also appropriating a vast percentage of the natural flow of water for their own uses. Total global runoff of freshwater is 40,700 km^3 annually, with only 12,500 km^3 actually accessible for human use. Currently mankind uses approximately 2,285

km^3 or 18% of the total accessible runoff (AR). Projections forecast human appropriation of approximately 9,830 km^3 or over 70% of AR annually by 2025, assuming per capita water consumption remains constant in the future. The effects of this enormous increase in water appropriation will inevitably cause the further decline of fish populations and extinction of many species [6]. Although world energy consumption and accompanying global warming are serious concerns, it could be the need for water that limits local and global economic development. The increasing pollution of world water bodies, particularly in light of the rapid growth of Asian economies, is another enormous problem. China in particular is at risk with damage to natural ecosystems so severe that the recovery of these systems, even with extreme shifts in policy and activity, is very unlikely. Humans are appropriating a massive proportion of ecosystem goods and services and dumping staggering quantities of waste to air, water, and land. Yet humans are just one of an estimated 5 to 30 million organisms [7].

The signs of planetary stress are clear. Earth's average temperature in 1995 was 15.39°C, the highest recorded average annual temperature. The ten warmest years in the last 130 years have occurred in the 1980's and 1990's. Insurance industry payouts in the U.S. for weather-related damage have climbed from US$16 billion in the 1980's to US$48 billion thus far in the 1990's [8]. Acid rain is threatening both freshwater fish and forests due to the emissions of sulfur and nitrous oxides from the combustion of fossil fuels in power plants and automobiles. Species extinction rates are 100-l ,000 times higher than before the arrival of mankind with a potential acceleration to 1,000-10,000 times higher if now-threatened species become extinct in the next century [8]. Far fewer species exist and the complex web of life created through billions of years of evolution is being unraveled in just a few hundred years. Logging, mining, agriculture, and grazing are degrading watersheds. Over 85% of U.S. inland waters are artificially controlled. Over half of U.S. wetlands, excluding Alaska, have been drained but only recently has their essential roles in stormwater control, biodiversity maintenance, and clean water become evident. The alteration of planetary systems has potentially dire consequences for humankind because of the wide range of services that natural systems provide that benefit humans and human settlements (Table 1). The value of these services is estimated to be US$33 trillion annually, with a range from $US 16 trillion to $US54 trillion per year. World economic output is approximately $US18 trillion per year, giving a ecosystem-to-GNP ratio of about 1.8. Although placing a monetary value on natural systems is abhorrent to some, it is also true that decisions are often made on the financial consequences of an activity, whether in the public or private sector [9].

Air quality enhancement/maintenance
Soils for food, wood, and paper production
Ambient temperature enhancement/maintenance (hot weather moderation)
Dampening flood peaks
Filtering and recharging groundwater
Reduced urban-chimney effects
Erosion control (cover, slope component, rainfall, wind, and soil texture components)
Renewable energy sources (solar, wind, biomass, geothermal, tidal)
Tree, bush, and flower pollination
Albedo change forces (energy budget for plants and animals)
Providing evapotranspiration cooling and shade for animals, people, and buildings
Food and water for wildlife
Dampening vertebrate pest damage to crops and other land production
Recreational and tourism areas and area access
Grazing for domesticated animals
Providing noise barriers and separation
Natural fires (for secondary succession conditions)
Carbon, energy, and water storage
Hazard reductions of several types

Table 1 Goods and services provided by natural systems

4 Resource Depletion

At present all signs point to rapid depletion of both renewable and non-renewable resources. While economies are using materials and energy more efficiently than in the past, the sheer number of people is causing total materials and energy consumption to rapidly increase. Forests are being depleted at an accelerating rate, from 40% of the earth's land surface 1,000 years ago, to 30% in 1900, and only 20% at present [8][10]. In addition to the loss of 1 acre per second of rainforest, temperate forests are being destroyed at an equally astonishing rate. Each year 4 million hectares of forests in Siberia and 1 million hectares in Canada are being lost. World grain production per capita has already peaked, with 465 million tons in 1987 adequate for 104 days use, shrinking to just 229 million tons, adequate for 48 days use in 1996 [9]. World fishery productivity has also peaked, growing from 22 million tons in 1950 to 100 million tons in 1987 with only 90 million tons in 1995. Large numbers of ocean species are under threat of extinction including sharks, orange roughy, blue fin tuna, beluga sturgeon and grouper. Worldwide, soil erosion is occurring at 25 billion tons/year, a rate far exceeding the ability of natural regeneration, making it essentially a nonrenewable resource [11].

5 Issues of Waste and Pollution

Humans are the sole species whose waste is not the food or a resource for another species and the waste generated by human activities is enormous. U.S. municipal solid waste ranges from 125-200 million tons depending on the source of the information. Construction and demolition (C&D) waste per capita in most OECD countries is about 0.5 tons or approximately 125-130 million tons annually in the U.S. compared to the official estimates of U.S. C& D waste of 25 million tons per year. Industrial waste in the U.S. amounts to 12 billion tons on a wet basis. Virtually all this waste is sent to engineered landfills with an insignificant recycling or reuse. Materials extracted from the earth's crust and then concentrated for industrial purposes do not simply disappear as a consequence of human activity because the earth's matter is essentially constant. It is the dissipation of high quality, concentrated materials that causes many of the world's environmental problems, including heavy metals that tend to buildup in river bottom sediments. This dissipation effect corresponds to entropy in thermodynamics, a conversion from useful to useless [12] [13].

6 Strategies for Sustainability

Some economists from a new school of thinking known as ***ecological economics*** suggest that the world economy must attain a ***steady-state*** condition where the matter-energy throughput reaches a sustainable level, with a good quality of life and constant income level for individuals, and a stable world population. This clearly conflicts with the underlying assumption of sustainable growth of the economy. Another vision suggests that the economy can continue to grow if low resource consuming sectors such as services, information, culture, education, and finance are the basis for growth rather than material-energy intensive industries [8]. To provide the bare essentials for the world's current population would require a factor of ten increase in economic activity. Technology will have to improve by a factor of twenty to maintain current levels of environmental burden [14]. The Rocky Mountain Institute and the Wuppertal Institute provide evidence that a factor of four increase in resource efficiency is achievable with existing technologies, giving at least a modicum of hope that the world can move far closer to sustainability [15].

One line of thinking on how business and industry can shift onto a path of sustainability is for companies to accomplish this change in three stages. Stage One would be a shift to pollution prevention from pollution control, driven in part by new international standards such as IS0 14000. Stage Two would be product stewardship, with emphasis on minimizing the life cycle environmental impacts of products using concepts such as Design for the Environment (DFE). Stage Three involves the development of clean technologies, changing the technology base from one that depends on unsustainable behavior to a base that is inherently in sync with natural systems. The very rapid growth of the world's economy, particularly in Asia, is creating substantial environmental problems but also an enormous opportunity to leap ahead technologically to clean processes [16]. The backdrop to this shift in OECD countries is the condition of economies in poorer nations. The economies of these nations cause deforestation, soil erosion, desertification, and species extinction because survival has priority over the protection of valuable ecosystems. The need to survive and the absence of economic growth are resulting in massive environmental impacts in countries whose populations are 75% of the world's people [15].

7 Increasing Resource Efficiency and Reducing Waste

One of the key questions that must be answered in the short term is the role of technology in increasing resource efficiency. It is thought that near-future technologies can dramatically increase resource availability and efficiency [15] [17]. The commonly mentioned increase in resource efficiency to achieve worldwide sustainability is a factor of 4 to 10, depending on the source of the information and the resource involved.

7.1 Materials

Humans are now responsible for more materials movement than geological and weather forces combined. While there has been obvious concern over small quantities of very toxic substances introduced into the biosphere by human activities, what has remained unnoticed is the ***ecological*** *rucksack* of materials as described by Friedrich Schmidt-Bleek of the Wuppertal Institute. Megatonne quanitites of material movement must be examined in addition to the microgram quantities of especially harmful substances. Materials Intensity Per Service (MIPS) is one measure of the efficiency of materials use with MIPS for gold being 1:350,000, that is, 350 kilograms of materials processing produces one gram of gold. MIPS for cement is 1: 10, far lower than gold but huge quantities of cement are produced annually worldwide. Schmidt-Bleek estimates that a factor of ten improvement in MIPS in OECD countries must be achieved to reduce the consequences of the ecological rucksack and create a sustainable flow of materials [15]. This is achievable only through extensive reuse and recycling of materials and other measures that minimize the dissipation of previously concentrated materials.

Significant progress has been and continues to be made in the dematerialization of industrial economies. Today automobiles are far lighter, fiberoptics transmit vast quantities of information at a fraction of the weight of copper wiring, computers are smaller and lighter, and the use of aluminum and plastics has significantly reduced the mass of packaging and many common products [17]. However these reductions in MIPS are more than offset by increasing consumption and population and total materials consumption continues to rise.

7.2 Energy

Overall energy efficiency of industrial economies is about 5%, due largely to the number of stages of production (resource extraction to delivery of end service) and the relative inefficiency of each stage. Ultimately, overall efficiencies could approach 50% if the number of stages is reduced and stage efficiencies are greatly increased, both of which are feasible to accomplish [17]. Significant progress has been made in reducing energy use. Although energy use in the U.S. remained relatively flat between 1973 and 1986, economic production expanded by 40%. Similar developments occurred in Japan, the United Kingdom, France, and Germany [4].

8 Applying Sustainability to Construction

If sustainability principles are to apply to industry, government, and the economy, it is clear they must also apply to construction, an industry whose end products consume a significant proportion of all materials and energy in their creation, operation, and deconstruction. In the U.S., the construction and operation of the built environment consumes in excess of 30% of all energy and 40% of the materials produced by the economy. Compared to other commercial activity, construction may be the one least able to respond to a shift toward sustainability, due largely to the nature of its creation. Unlike automobiles, most buildings are for the most part unique and are assembled from a combination of manufactured goods (windows, doors, air handlers, transformers), products tailored for the processing on-site (lumber, gypsum board, roofing, electrical wiring, conduit, ductwork), special liquids with low mass (paint, glues, mastics, sealants), and items that are comprised largely of raw materials moved in bulk to the construction site (fill materials, aggregate, concrete). Each building is assembled on-site with little thought to its final disposal. Much effort has been invested in reducing the operating costs of buildings and technology has been developed to reduce energy and water consumption. However little or no investment has been directed toward creating a systematic and standardized DFE strategy for buildings. Environmentally sustainable design and green building efforts have focused on energy and water consumption, indoor environmental quality, and some methods of reducing building impacts on the local environment during construction and operation. But again, there has been virtually no effort devoted to designing all components and the entire structure for ultimate disassembly for component reuse or recycling. For sustainable construction to evolve, the built environment must be rethought using the ideas emerging from industrial ecology (IE) and DFE. The result, in addition to the significant progress resulting from ESD, sustainable construction, and green building movements, would be structures that are designed with total reuse or recycling of all materials as a front-end goal. For materials, this thinking must be instilled at three levels of design. First, all materials in buildings must be recyclable or the components they comprise must be reusable. Second, all manufactured products must be easily disassembled for recycling, implying a standard labeling system that identifies the materials in each component. Third, the building itself must be designed for easy, future disassembly. Similar to IE, all activities involved in producing the building must provide for the recycling of waste created during the construction process. Shifting to on-site manufacturing plants designed to minimize and recycle waste could help achieve this end.

Building design itself must be transformed for sustainability to be adequately addressed. The fundamental principle to be followed is that the best protection that can be afforded natural systems is to use as little material, energy, water, and land resources as possible. Minimizing resource consumption is the maxim that designers must follow to cause this to occur. The ingredients for success include (1) excellence in planning, (2) design of adaptable, durable structures, (4) extensive application of passive energy design, and (4) incorporation of high efficiency energy consuming systems using renewable resources.

Well thought out planning insures buildings will maintain their purpose for long time frames without the need for their removal. Proximity to multi-modal transportation comprised of mass transit and bicycle routes is one of the crucial steps to reducing reliance on automobiles for transit. Mixed use communities are also a necessity and the Transit-Oriented Development (TOD) and Traditional Neighborhood Development (TND) movements in the U.S. are encouraging bicycle, pedestrian, bus, and light rail transit over automobile use.

Long life, durable, adaptable structures provide by far the best means of minimizing materials consumption. Employing DFE will ensure the materials in these structures can be readily reused and recycled. Passive energy design and high efficiency energy systems can reduce energy consumption to the absolute minimum. Low flow fixtures, greywater and rainwater harvesting systems can minimize water use. Excellent interior environmental quality promotes the health and increases the productivity of the occupants. Finally, high quality design provides the building with an inherent character that society will value, prolonging the desire to preserve their use for the long term. Excellence in planning and design provides the foundation for a sustainable built environment. Adhering to these principles would produce sustainability in construction.

References

1. Daily, G.C. and P.R. Ehrlich (1992) Population, sustainability, and earth's carrying capacity, *Bioscience*, 42:761-771.

2. Hardin, G. (1968) The tragedy of the commons, *Science*, 162:1243-1248.

3. Lovelock, J. (1988) *The Ages of Gaia: A Biography of Our Living Earth, New* York: W.W. Norton & Company.

4. Sagoff, M. (1995) Carrying capacity and ecological economics, *Bioscience*, 45:610-620.

5. Vitousek, P.M., P.R. Ehrlich, A.H. Ehrlich, and P.A. Marson (1989) Human appropriation of the products of photosynthesis, *Bioscience*, 36:368-373.

6. Postel, S.L., G.C. Daily, and P.R. Ehrlich (1996) Human appropriation of renewable fresh water, *Science*, 271:785-788.

7. Brown, L.R., C. Flavin, and H. Kane (1996) *Vital Signs 1996, New* York: W.W. Norton & Company.

8. Wilson, E.O. (1989) *Biodiversity*, Washington, D.C.: National Academy Press.

9. Costanza R., et al. (1997) The value of the world's ecosystem services and natural capital, *Nature*, 387:253-260.

10. Bates, A.K. (1990) *Climate in Crisis*, Sydney: The Book Publishing Company.

11. Brown, L.R. and E.C. Wolf (1984) Soil erosion: quiet crisis in the world economy, *Worldwatch Paper* 60, Washington, DC: The Worldwatch Institute.

12. Ayres, R.U. (1993) Cowboys, cornucopians and long-run sustainability, *Ecological Economics, 8:* 189-207.

13. Georgescu-Roegen (1971) *The Entropy Law and the Economic Process*, Cambridge, Massachusetts: Harvard University Press.

14. Hart, S.L. (1997) Strategies for a sustainable world, *Harvard Business Review*, 75:67-76.

15. von Weiszäcker, E., A. Lovins, and H. Lovins (1997) *Factor Four: Doubling Wealth, Halving Resource* Use, London: Earthscan Publications Ltd.

16. Myers, N. (1993) The question of linkages in environment and development, *Bioscience*, 43:306.

17. Ausubel, J.H. (1996) Can technology spare the earth? *American Scientist, 84:* 166-178.

Challenges and Opportunities in UK Housing into the next Century

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Abstract
Issues concerning the location of new housing and demographic trends serve to highlight the challenge faced by the UK in reducing carbon dioxide emissions to a sustainable level. Statutory and voluntary energy initiatives are referred to as examples of the ways in which the UK Government is tackling the problem.

Current UK Best Practice in the housing field is illustrated by 'a review of ultra-low-energy homes' carried out in 1995, which produced two reports containing examples of low energy and environmentally responsible dwellings. Key aspects of the design of low energy houses using a range of construction systems are highlighted. Built examples are referred to such as the urban autonomous house in Nottinghamshire by Robert and Brenda Vale and The Berm House, Field and Conference study centre in South Wales. New research initiatives into sustainable building practices such as Sherwood Energy Village (a proposed net zero CO_2 autonomous community in Newark and Sherwood), Nottinghamshire will serve to highlight the possible future direction of Best Practice in the UK.

Multi-disciplinary and inter-disciplinary working practices are referred to with reference to the writers participation in a new 'Interdisciplinary Design for the Built Environment' course at Cambridge University in England. The aims of the course are to encourage consultants from a range of backgrounds including Architects, Engineers, Quantity Surveyors and Transport Planners to participate in building design team groups. This part of the paper attempts to define a possible 'way forward' in terms of interdisciplinary or team working methods as a contribution to better working practices and a more sustainable future for the construction industry.
Keywords: UK energy initiatives, Best Practice, Interdisciplinary Design.

1.0 Introduction

This presentation will focus on 3 themes:

- Methodologies and Regulations, highlighting current UK Government regulatory and non-regulatory frameworks for energy conservation and the reduction of emissions of carbon dioxide.
- Open Design and Production Process, citing Best Practice examples of low energy housing in the UK.
- Management and Organisation explaining how interdisciplinary working practices may provide opportunities for producing more sustainable buildings.

2.0 UK energy consumption

The UK is an area of relatively high CO_2 emissions from fossil fuel combustion in relation to population. The UK has 1% of world population and approximately 2.5% of CO_2 emissions. The total energy expenditure in the UK is over f52 billion per annum, of which about 41% is used in buildings, slightly less than the transport sector but significantly more than the industrial sector.

Looking at the buildings sector in more detail, housing is the single largest consumer of energy accounting for some f 14 billion per year (65%) – the same order of magnitude as defence expenditure or education.

3.0 Transport and planning

One of the key issues with regard to sustainability is that of transport planning and land use. The Royal Commission on Environmental Pollution (1994) stated that: The unrelenting growth of transport has become possibly the greatest environmental threat facing the UK and one of the greatest obstacles to achieving sustainable development.

The Government has published a guide to Planning Policy Guidance Note 13 [1], which looks to reduce dependency on private motorised forms of transportation. This document emphasises greater integration of land use and transport planning by:

- Minimising travel distances
- Encouraging modes other than the car
- Improving accessibility to facilities

Ideas regarding the form of new settlement patterns, which may help to reduce transport dependency and reduce pollution, are emerging. These include pedestrian pockets, urban villages and compact urban forms. Taking the urban village as one example, this comprises good transport links with a rail network passing between the villages. There are local shops at the cores and all housing is within 5 minutes walk of local amenities. This starts to address the problems of transport dependency - putting more into good public transport, encouraging people to walk and cycle. It is important to remember that it is pointless getting the detail of house design and construction right if the savings being made in house running costs are offset by increasing energy expenditure in transport.

Most of our towns and villages in the UK are already built so we will also need to think about regeneration in urban areas. Research suggests that urban compaction or the compact city may offer the best solutions to reducing private travel. Densities below 29 persons per hectare tend to increase transport energy use [2].

High density urban living in attractive urban locations with perhaps revised planning rules for reducing car parking densities would provide safer and more attractive places to live. Maisonette type accommodation with urban greenery and limited parking provision outside the dwellings is one type of development which may be appropriate in inner city areas.

Demographically, by the year 2016 an estimated 4.4 million new households [3] will be needed in the UK of which about 3.5M will need to accommodate single people. The Joseph Rowntree publication entitled '21st Century Homes Building to Last' [4]. discusses these trends in greater detail and in particular questions whether we should be building for more diverse and sophisticated needs of homeowners. House types should be flexible enough for people to adapt as their needs change in the future.

4.0 Housing energy initiatives

In the UK, there are a number of key Government statutory and non-statutory energy initiatives and I would like to talk about 2 of them:

- The SAP [5] introduced into the UK Building Regulations in 1995 and therefore mandatory for new housing.
- The Environmental Standard - The Building Research Establishment's Environmental Assessment Method (BREEAM), for new housing [6] - a voluntary standard.

4.1 The Standard Assessment Procedure (SAP)

The SAP is the Governments preferred method of Home Energy Rating and is based on BREDEM 12, the Building Research Establishment's Domestic Energy Model. It is a simple 1- 100 scale, the nearer to 100 the more energy efficient the house.

SAP can be used as a method of compliance in the Building Regulations. To demonstrate compliance the SAP rating needs to be between 80 and 85 depending on the area of the dwelling. For example a dwelling of 80 sq. metres will need a SAP rating of 80 to comply, while a dwelling of 120 sq. metres would need a SAP rating of 85 to comply using the Energy Rating Method.

However, there are alternative methods of compliance and there is no obligation to achieve a particular SAP rating. Higher U-values are justified for the roof, floor and windows of dwellings having SAP ratings of 60 or less.

SAP has necessitated those working in the housing energy field to consider a more holistic, integrated approach to house design. Consideration needs to be given to heating, fabric and ventilation issues together.

4.2 The Building Research Establishment's Environmental Assessment Method.

BREEAM is intended to translate the rather general principles of sustainable development into specific requirements which can direct and influence action.

BREEAM sets out technical performance criteria for buildings, components, systems and materials. BREEAM is a voluntary, self-financing scheme for the environmental labelling of buildings developed by the Building Research Establishment with private sector partners and sponsors. Individual buildings are awarded Certificates based on the performance of the building against a set of defined environmental criteria.

This certificate can be displayed in the building, or used in the promotional portfolio, and may form part of the developer and occupier's overall environmental policy statement and management system. BREEAM is now international, with schemes being launched in Canada (1996) and Norway (1995) based on BREEAM. Countries such as New Zealand, Australia, Sweden and South Africa are discussing developing versions of BREEAM for their particular climate, social and market conditions, and national priorities.

BREEAM for new housing was renamed The Environmental Standard Award in 1995. This seeks to minimise the adverse effects of new homes on the global and local environment while promoting a healthy indoor environment.

The environmental assessment, which is carried out at the design stage, is based on readily available and generally accepted information. The method, which provides a pass/fail assessment, identifies and credits designs where specific targets are met. Designs are not expected to gain credits for every issue assessed. Assessors licensed by BRE carry out assessments. Where large numbers of buildings are to be assessed, developers may apply for a licence to assess their own buildings.

5.0 Review of ultra-low-energy homes in the UK

In 1995 the Building Research Establishment instigated a review of ultra-low-energy homes [7 and 8] to identify examples of low energy sustainable homes. The aim of the review was to identify 40 ultra-low-energy homes in the UK and 12 from overseas.

The criteria adopted for the selection of UK schemes included:
* Fabric U-values of 0.2 or less
* Glazing U-values of 2.0 or less
* A well sealed construction
* Total delivered energy of less than 100kWh/m^2 per year
* Innovative or unusual construction techniques or heating systems and schemes of particular architectural merit

Obviously only the very best schemes can satisfy all these criteria. Many of those included fall short in some areas but are included because they are good examples of particular construction techniques or one of the other criteria. A large number of the projects identified are in South East England, particularly the Milton Keynes areas.

The research examined various external wall construction types and examples are categorised into:
* Masonry
* Timber frame
* Steel Frame
* Concrete
* and earth-sheltered construction.

5.1 Masonry

The Autonomous Urban House, Southwell, Notts 1993. Designed by Robert and Brenda Vale. Almost totally self-sufficient in its energy use. Features include stored and filtered rainwater, collected from the roof via copper rainwater goods. There is also a cornposting toilet and a soakaway for grey water. The total measured energy consumption for the house is about 22kWh per m^2 year and this is impressive when you consider that there are only a handful of schemes in the UK that are under 100 kWh/m^2.

The external walls from inside the conservatory, is double-glazed. The windows in the external walls are triple glazed. There is through the wall mechanical ventilation and heat recovery units in 'wet' rooms taking preheated air from the conservatory. In most aspects, it appears that the standard of living achieved in this house is on a par with typical UK households. The local planning authority has become extremely enthusiastic about the house. It has a stated policy of achieving another 100 houses of this type by the year 2000.

The external wall construction comprises an inner leaf of 100mm dense concrete block with 25Omm built-in mineral fibre bats and plastic ties. A brick facing was used on the outside and this achieves a U-value of 0.14. The builder's total price for constructing the house including the purchase and installation of the PV system was about f 155,000.

Creswell Road, Darnall in Sheffield. The client for this project was North Sheffield Housing Association. The project consists of 2 semi-detached houses. Each house is $88m^2$ but built with no additional cost when compared with equivalent standard houses. Infact, there was a minus overcost and the surplus funds were used to make the houses larger than normal. The lowest tender received to build the scheme was £3,000 per housing unit below the Housing Corporations normal budget per unit.

The external wall construction briefly comprises aerated concrete block, 150mm built in mineral fibre bats with clay brick outer skin. The external wall achieves a U-value of 0.2 1. The roof consists of 400mm of cellulose fibre and there is a further 150mm of insulation in the floor. Note that instead of using a cavity closer the insulation is continuous which avoids problems of thermal bridging. Independent lintels also minimise thermal bridging.

Dr Susan Roaf's residence in Oxford. The north front of the house is unremarkable in many respects. The clue that this is no ordinary house is parked outside the front of the house - an electric car powered by a PV array which has a range of about 50 miles and ferries the owner to and from work.

On the south side of the house there is a PV array that powers the electric car and passive solar design to maximise solar gain. The house also utilises flat plate solar collectors for water heating. The total costs of the house incorporating this range of technologies are around £$800m^2$. There is a question mark regarding cost effectiveness and payback with such technologies in the UK at present but perhaps you might expect a house utilising a range of new technologies to be more expensive initially.

The more widespread adoption of such technologies will help to reduce costs and encourage their wider adoption.

The specification for the house briefly comprises:

Occupied area - 233m2
Roof U-value = 0.14
Walls U-value = 0.22
Ventilation = 0.5 ACH
Ground U-value = 0.19
Windows U-value = 1.3
Solar hot water - 4kW peak

5.2 Timber frame

The timber frame example is from the Futureworld exhibition in Milton Keynes being a 2 bed detached house built by Admiral Homes. The extraordinary think about this scheme is that it is the only all electric house that has achieved a BREEAM 'excellent' rating – the highest possible.

The external wall construction consists of double stud construction with a total wall thickness of 460mm. From the inside we have 12mrn plasterboard with a 50mm service cavity behind and a polyethylene vapour barrier. Then a total of 235mm of mineral fibre compressed within the stud construction, plywood sheathing, breather membrane and a 50mm clear cavity. On the outside 102.5mm brickwork. This wall construction achieves a U-value of 0.15. The construction cost was about 20% more than Admiral Homes usual speculatively built timber frame houses.

5.3 Earth sheltered examples

An earth-sheltered example is the *Caer Llan Field Study and Conference Centre, Monmouth 1987.* The project was conceived in 1980, the aim being to reach zero space heating energy. This was achieved with a normal annual range of temperatures for the guest rooms varying from 17.5 to 24.5°C. Although there is no space heating, ventilation has to be provided mechanically. Ducts run the length of the building in the solar corridor and supply air to the rooms recovers a certain amount of heat from the exhaust air. The insulation slabs throughout the building are sealed at seams with in-situ polyurethane foam.

The second earth sheltered example is *Hockerton Houses, Southwell, Notts. 1995* designed by Robert and Brenda Vale. This comprises five terraced houses each $122m^2$. The local planning authority gave the scheme planning permission in the open countryside on the grounds that its environmental benefits outweighed the disadvantages. It features triple glazing, solar water heating and no space heating. The external wall on the south side is a timber framed conservatory, which will obviously allow passive solar gain.

5.4 Sherwood Energy Village

Sherwood Energy Village is intended to be an exemplar model for a sustainable community. The energy emphasis of the village builds on its past as a provider of energy based on coal and looks forward to a future based on renewable energy. The village will be serviced from local resources and could lead to a considerable degree of autonomy.

To achieve this, the layout of the village will aim to minimise the need for transport and allow the growing of food. The basis of the village will be the concept of increased autonomy. Some of the houses at Sherwood Energy Village will be independent of mains sewerage and water.

The detail is still being developed but the intention is that the site generates energy, provides its own water and deals with its own waste. The layout will benefit from south facing solar gain and it is intended that there will be some use of photovoltaics for electricity generation. The houses are quite ordinary in many respects. An integrated package of energy efficiency measures includes super insulation and very low space heating demand. The scheme will consist of 62 units built at reasonable cost.

5.5 Summary

Summarised, the main points of the review of ultra-low-energy homes are:

- The majority of schemes are in SE England and obviously a large number in Milton Keynes which is renowned for its low energy housing.
- Only about 4 schemes achieved under $100kWh/m^2$ energy consumption. This was partly due to inadequate heating system specifications and high air leakage rates.
- Some examples had innovative detailing and novel construction.
- Some of the houses are utilising mechanical ventilation systems to achieve the air change rates required and passive stack systems are also in use.
- Costs vary enormously. The range of costs in the houses reviewed was from about f $250m^2$ up to over f $800m^2$.

Interdisciplinary design for the Built Environment

The writer has recently completed an Interdisciplinary Design for the Built Environment Course at Cambridge University in England. The course is a response to an increasingly . widespread belief that the complexity of the problems facing the designers of the built environment cannot be met solely from the confines of existing professional roles.

Bringing together groups of professionals in multidisciplinary teams encourages teamwork and collaborative design. The Course encourages designers of the built environment to improve the efficiency of the industry and at the same time care for and enhance the wider environment (natural and man-made) in which they work. This is achieved by setting up Interdisciplinary teams at the early design stage of projects enabling input from a range of backgrounds. This enables the form and layout of proposals to benefit from the experience of a range of expertise. Examples include the early input of the Client to determine the optimum location and phasing of development on a major site in Cambridge. As an Architect, my primary concern was to achieve quality of space in the masterplan. My experience did not extend to which parts of the site might prove most lettable. However, I was familiar with ideas of compactness, urban villages and the importance of variety in urban space. This set up a dialogue between two people of differing backgrounds and inevitably requires compromise in the type of final solution agreed upon.

A second example is the important interface between Architect and Services Engineer. Traditionally, the Service Engineer may not be brought in to a project at an early stage. This may lead to the Services aspect of the building being applied to the design at a late stage. The Interdisciplinary approach favours the Services Engineers input being utilised early in the project. This allows consideration of the services aspect of the design to be truly integral.

I anticipate that the Interdisciplinary approach will prove successful in the UK. The Course is still in its infancy but has already attracted people from a wide range of disciplines and backgrounds. Regular Conferences provide a forum for feedback and debate for students on completion of the Course. The Course itself comprises lectures from leading Practioners in the field delivered at residential periods at Cambridge over two years part-time. I commend this approach to other Consultants in the field.

7.0 Conclusions

This paper has highlighted the challenges facing the UK in achieving more sustainable housing. UK Government energy initiatives including the Standard Assessment Procedure and The Environmental Standard are raising awareness among those involved in house construction.

A review of ultra-low-energy built examples suggests that there are now a significant number of such homes in the UK utilising a variety of construction systems and environmentally beneficial features such as low embodied energy and water saving techniques. The study highlighted the fact that there are still relatively few houses using less than 100kWh/m^2 energy consumption. This is due mainly due poorly commissioned heating systems and high air leakage rates.

The writers participation in an Interdisciplinary Design for the Built Environment Course at Cambridge University has pointed to a future based on a better understanding of the role of other disciplines in the built environment. Creating sustainable environments and buildings will require input from a range of expertise each sharing common goals. These might include targets for building energy consumption, proximity to public transport and so on. Solutions will undoubtedly lie in contributions made by multi-disciplinary teams, members of which will have been involved early in the design process.

1. PPG 13 A Guide to better practice (1995). *Reducing the need to travel through land use and transport planning. HMSO.*
2. Newman P, and Kenworthy, J (1989). *Cities and Automobile Dependence – An International Sourcebook.*
3. Housing and urban capacity, *(* 1995). *Projections of Household Growth in England to 2016.* UK roud table on sustainable development. HMSO.
4. Rudlin D. and Falk Dr. *N* (1995). *21st century Homes Building to Last.* London. URBED.
5. The Standard Assessment Procedure *(1994). The Government's Standard Assessment Procedure for energy rating of dwellings.* BRECSU, HMSO.
6. BRE (1995). *Environmental Standard. Homes for a Greener World.* Building Research Establishment, Garston, UK.
7. BRECSU (1996a). *A review **of** ultra-low-energy homes, A series **of** UK and overseas profiles. General **Information** Report* 38. BRECSU, HMSO.
8. BRECSU (1996b). *A review **of** ultra-low-energy homes, 10 UK profiles in detail. General Information Report 39.* BRECSU, HMSO.

A Simulation of the Urban Environment in Salford

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Abstract
This paper argues the case for a new type of computer based simulation of an urban environment and gives an account of a project to build such a simulation. The Chapel Street redevelopment area in Salford, in the North West of England, is to be used as the prototype. The simulation will model economic, environmental and social factors of life in this area, using a holistic approach, so that the regeneration can be analysed and projections into the future can be made, which will inform planning and policy making.

We review current city models which we categorise as “analytical” and “graphical”. The strengths and weaknesses of these models are noted. A design for a new type of city simulation is put forward that builds on the strengths of current models and avoids their weaknesses. The approaches and technologies needed to build the new city simulation are considered and a plan for implementation is put forward.

The simulation will be implemented using Case Based Reasoning (CBR) Expert System software that will “learn” from use, reducing development time and facilitating continuous development. This feature will enhance the modelling of changing social parameters to provide a dynamic view of human activity. To enhance usability it will have a graphical interface.

The simulation will draw on our current work. Presently we are working on a cross cultural comparison of local Agenda 21 strategies, in Chapel Street in Salford and Spina 3 in Turin in partnership with Turin Polytechnic. We are also co-ordinating the pan European BEQUEST network concerned with the evaluation of the quality of urban life. These projects, involving a number of European partners, are informing our conceptual model of a city. We will also make use of innovations in Case Based Reasoning, including the linking of CBR to Virtual Reality on the Internet, that are the result of IT research at Salford. This work will be the basis of the modelling engine to be constructed, and the interface to the engine. We are taking a soft systems approach to building up the conceptual model that will be the basis of the modelling engine.

We aim to meet the needs of planners, policy makers, and citizens, by taking a holistic approach to model design, using appropriate new technologies, and also incorporating the best features of existing analytical and graphical models.

Keywords: city, environment, model, simulation, sustainability, urban, virtual reality

1 Introduction

Cities are dynamic living organisms that are constantly evolving. Thus city planning has always been difficult. Today our rapidly changing society makes the job of predicting future needs of city dwellers, and those who depend on the services cities provide, even more problematic. Particular problems include: transport, pollution, crime, conservation and economic regeneration. Furthermore, in planning for the future, it is essential to take a holistic view of the sustainability of cities, as identified in Agenda 21, [1]. Thus in addressing the complex problems of city planning it is not sufficient just to be concerned with the physical structure of the city; the interplay of intangible economic, social and environmental factors needs to be considered as well, [2].

Those involved in the sophisticated art of city planning use a variety of tools. These already include city models. It is useful to review what is currently on offer in city modelling in order to inform the design process of new models.

2 A review of current city models

We have categorised current city models as "Analytical" and "Graphical". Analytical models process quantifiable data to give indicators of city life, for-example, expected pollution levels associated with particular fuel use and traffic flows. Graphical models show what an existing cityscape looks like, and can generally incorporate- renditions of proposed developments to display possible future cityscapes. Examples of these models are discussed below.

2.1 Analytical models: Leeds and Cardiff

The Leeds Quantifiable City is a typical analytical model. Work is still in progress on this model produced by the Environment Centre of Leeds University with over £1 million of research grants over the last 10 years. The aim of the project is to develop a computer model of urban processes that can be used to promote urban development along a sustainable path. The framework for the model is made up of sub systems of the Human Economy, City Metabolism, Ecological Integrity and vitality, and the quality of human life. On this framework a picture of resource use, residuals arising (waste and pollution), and transport is built up. The system monitors people, flora and fauna, renewable and non-renewable resources, and climate. The output variables are sustainability indicators "which are expressed in fine detail", [3].

Leeds University have continued to keep the strong support of the city authorities and it is clear that this comprehensive city model is of value in urban planning. However in a frank discussion with the authors, Professor David Kay of Leeds University, who is a key researcher in this project, pointed out some of the problems with this type of model. These are discussed later in this paper.

The Cardiff model, formally called the Energy and Environmental Prediction model or EEP, is the work of the Welsh school of Architecture. This model is primarily designed to model energy use, the production and dispersal of pollutants, and the health effects of the pollutants. It is to be installed in Cardiff and is being assessed for use in Newport. Camden Borough and Leicester City council have recently become involved with the development of this model, [4]. Both-the Leeds and Cardiff models are funded by the UK research council, EPSRC, and work is presently under way to integrate the modules of these models.

2.2 Graphical models: Edinburgh and Bath

The Edinburgh model was commissioned by the city's Old Town Renewal trust in 1993 and built by ABACUS at Strathclyde university. Being one of the earliest virtual cityscapes, this is now well developed and also well integrated in the planning process. To obtain planning permission in the old town it is now mandatory to supply a CAD model of the proposed development in the appropriate format for it to be dropped into the virtual cityscape.

The Bath Model was produced by the Centre for Advanced Studies in Architecture (CASA) at Bath university using Virtual Reality techniques. Architects and developers now buy sections of the model in which they can place their own proposals and display them to planners and the public. The Bath model was one of the first to be available over the Internet without specialist equipment. Inevitably the quality of the display suffers, due to delays in transmission, but the model makes the point that public perception of a proposed development can be greatly enhanced by the use of this technology, [5].

2.3 An assessment of Analytical and Graphical models

The above review only examines models produced in the UK. However the Leeds and Cardiff models are similar to analytical models produced elsewhere, [6]. Whilst local authorities are clearly benefiting from the analysis of the various aspects of the city incorporated in these models, it is also evident that the models have some weaknesses. Generally they suffer from being "static" in that they are both difficult to update and cannot easily be used to predict changes over a number of years, an essential criteria for strategic policy making. They rely upon those aspects that can be quantitatively measured and do not consider many other aspects that contribute to a good quality of life. Also as they were often designed at a time when there was little regard for the quality of software interfaces, they suffer in terms of usability. Thus their use is restricted to research groups and other highly trained personnel. Interpretation of output is also a problem: it is often unclear what the output of individual parameters indicates in holistic terms. To quote from the Leeds city model team "The problem of assessing the general direction of city development (sustainable or otherwise) using many indicators is acknowledged". This factor also accounts for another criticism of such models: that they are of limited use in forecasting. It is not possible to run the city on for 10 or more years to see how it would develop if a particular plan was put into action. Another problem with analytic models is their quantifiable nature. Although some models do make an attempt to incorporate qualitative factors these are of secondary concern, and do not enable a holistic view of the city.

In contrast to Analytical models, graphical models are generally easily accessible. However the feedback from graphical models is mostly limited to criticism of the visual impact of development proposals. Whilst this feedback could greatly enhance public participation in the planning process, it only addresses one aspect of that process.

Graphical models are developing rapidly and new features are being added, such as those in the Philadelphia model now under development, [7]. However when the Philadelphia model is completed it will effectively be a graphical model linked to an information system, no forecasting will be possible.

3 Towards a new type of city model

It would be useful to have a model that combined the positive attributes of analytical and graphical models but was also able to model qualitative factors and forecast holistic change in a city, rather than changes in isolated parameters, over a period of years. Some of the features of such a model are incorporated in the computer game Sim City.

Sim City was developed by Maxis ltd. a software company specialising in games. The Sim City player is presented on screen with a clear terrain on which to build the infrastructure and plan of a city, with the aid of a graphical toolkit. Services such as roads, railways, power, and water, need to be installed as well as public buildings (police stations, schools, etc.) and amenities. The player cannot build other buildings; instead areas can be zoned as commercial, industrial, and residential. Within the simulation, "Sims", the people who inhabit Sim City, will decide on the type of building, varying from high rise to low rise and humble to prestigious . If an area becomes particularly unpleasant e.g. high volumes of traffic, high crime, and high pollution, they will not build at all, or will abandon existing buildings. The parameters of Sim City are well integrated and thus the development of the city depends on the overall plan. Success can be measured in any way the player chooses. It is possible to plan cities that will develop dense urban areas and high rise offices, or garden cities with low pollution and traffic volumes. The user has freedom to experiment and gets feedback from the experiments.

Because Sim City is a game it is easy to overlook its sophisticated attributes. Most city models employ the *ceteris paribus* assumption, that everything remains the same while one parameter is being examined. However this is almost always false in the real life of a city.-Sim City eschew? this static approach for a dynamic one,-in simulating the evolving city as a whole. Compared to other city models Sim City incorporates a large number of economic, environmental, and social parameters. Furthermore these parameters are dynamically integrated. It would seem that modelling the interaction of these variables is an almost impossible task. However this is achieved in Sim City by approximation. Most Sim City parameters have few possible values, which in turn decreases the complexity of interaction, [8]. This introduces an interesting paradox into the model: accuracy of detail is sacrificed to give a "better" picture of the city as a whole.

The accuracy of this holistic picture is open to question. For instance assumptions are written into Sim City which cannot scrutinised by the user of the system. However the accuracy of what is avowedly a game should not detract from the merits of the modelling methods involved. There are problems with current analytical models in delivering a holistic picture. It could be argued that this is because they are concerned with too low a level of abstraction. It is as if they are trying to understand the behaviour of a complex living organism by studying the chemistry of its molecules. Checkland and Polyani both discuss the futility of such a task in their critiques of the limits of rational science, [9,10]. Checkland refers to "emergent properties" of systems as they are viewed at higher levels of abstraction. In his arguments for "systems thinking", he illustrates the problem of pursuing ever greater detail rather than thinking about a system at an appropriate level in an appropriate way.

The great merit of Sim City is the way it models city problems at a higher and more appropriate level of abstraction, enabling the modelling of radical changes to a city. For example a city can be planned with no roads, and only a rail based public transport system. When this is modelled in Sim City the immediate result is complaints by the city inhabitants followed by a decrease in prosperity. However after a few years prosperity begins to rise again and continues rising, presumably as the benefits of diminished pollution etc. influence the model. It can be argued that this is not a realistic outcome. That it is an outcome, and that the approach can be examined and improved in new models, is less contentious.

4 Design criteria for a new city model

What are the consequences of approaching the design of a simulation of a city at a higher level: sacrificing accuracy of detail in order to generate a holistic picture of the city capable of supporting forecasts?-An obvious consequence would be less reliability on outcomes from the model when considering the quantifiable aspects such as pollution levels. Would this make a holistic simulation unacceptable to planners?

In the consultations we have had with those working in city planning concern was expressed that we might present a single mechanistic view of the parameters that affect the city. It could be said that this concern favours holistic simulations. Furthermore it was argued that on many important aspects of city life it was impossible to get accurate data. On some aspects it seems that even approximations are difficult as different interpretations of cause and effect can result in widely varying estimations. This problem is predicted by existing research into Cognitive Mapping, [11].

These discussions open up another aspect of modelling not incorporated in any of the models we have looked at. This is the ability of the user of the model to set it up to reflect their own interpretation of qualitative aspects of city life. From our discussions it was felt that a configurable system would be welcomed as there are many opinions of cause and effect in the workings of cities. A further advantage would be the ability to see the effect of altered legislation so that "what if' simulations could be run in which national and local policies were changed. This aspect of city modelling would make it a tool for policy making and research into social concepts of city life. It also supports the scientific analysis of cities by conjecture and refutation, [12].

4.1 Meeting needs - uses of the city model.

The justification for this new approach to city modelling must be in meeting the needs expressed earlier in this paper. How is it possible to meet these needs with city models?

The most fundamental use is to display plans, and forecasts of their effects, to make the planning process more democratic and comprehensible. This mode of use is similar to the use of the Bath and Edinburgh models described above. However, by incorporating techniques such as colour coding, the model could also display features such as vehicle and pedestrian traffic flows, areas of high crime rate etc. Different development plans could be compared and a forecast run to show effects on traffic, crime rate, etc. in the years after the development was built. Whilst these forecasts may not have a high degree of accuracy, they could be used for comparative studies and to promote discussion about the possible outcomes.

5 Building a new city model

How can the design outlined above be realised? Our approach is to build a prototype simulation of a small area of a city. This is a selected part of the Chapel Street development area in Salford. The reason for building a small prototype is to concentrate on the conceptual model and its software implementation without being distracted by detail.

To realise the design, it is necessary to have:

* Software on which a city modelling engine can be built that will reflect the dynamic evolving nature of a city.
* A conceptual model, of what a city is, and what happens in it, that will be realised as the city modelling engine.
* Sources of data to inform and build the model.
* Interactivity with the modelling engine that promotes ease of interpretation of the simulation as a whole and enables configurability.

5.1 Software

Recent developments in Knowledge Based systems show potential in the construction of complex dynamic models such as cities. In particular Case Based Reasoning (CBR) can support City Modelling with the following features, [13,141:

* CBR can draw upon surveys and prior cases in order to construct the simulator,
* it will enable a simulator to be built for a domain where we accept that we do not yet fully understand the underlying causes and effects,
* it will enable the city model to acquire new knowledge and thereby handle an increasingly wide range of situations without complex programme maintenance.

In effect CBR systems are able to acquire new knowledge (i.e. learn) as new cases are acquired with time, [15]. Thus as research is carried out into the behaviour of the city, this could be fed into the model to give it greater veracity. A more important aspect of CBR's ability to learn is the potential to model the incremental changes in the environmental, economic, and social aspects of the city. This will enable the representation of the changing expectations of citizens. For example, in areas with wide climatic variations enclosed areas for shopping are becoming the expected norm. A predictive model must reflect trends in behaviour of those who live in the city. This is difficult with algorithmic or heuristic models which require constant expensive maintenance if they are to remain effective.

CBR can provide the two "new" features of our design: support for holistic models and configurability. CBR makes the best fit for the cases it receives, Thus, as long as new data is accurately related to existing data, and the data is otherwise validated, CBR is able to make predictions. Even when data is incomplete CBR will give results ranked in terms of percentage certainty. The properties of CBR also allow for the emergence of unforeseen changes which may be of value in understanding potential future traits in city life, For a user to configure the simulation they effectively make up their own "cases" and put these into the system.

5.2 A conceptual model

A key part of the modelling engine design will be to determine what a city is, and more importantly what it does. To identify the variety of interest groups that can inform us on the nature of the city we have used the work of ATEQUE, [16]. Furthermore, in carrying out this part of the research, we will be using the network of representatives of the ATEQUE groups that we are building up in the BEQUEST project. BEQUEST is a pan European network set up to evaluate the quality of urban environments, [17]. To analyse the information we receive from these sources we will use cognitive mapping techniques. To map out the concept of the city as a whole we will use the soft systems approach developed by Checkland, referred to earlier in this paper. This approach is used in order to make sense of complex systems that incorporate quantitative (hard) and qualitative (soft) aspects. The conceptual model will be flexible enough to incorporate dense, diversified and other city forms, [18,19].

5.3 Data

Data acquisition can be a time consuming and expensive aspect of modelling. Choosing to model a redevelopment area alleviates these costs, as much of the data used in the model will be generated by Salford Council and their consultants as work proceeds in Chapel Street. To provide a physical framework to the model we will be using digital maps as supplied by the UK ordinance survey, and the National Geospatial Database.

These primary sources will be supplemented wherever possible by data collected for other projects. This includes existing city models, the Environmental Change Network Database, [20] and when it becomes available, the UK National Land Information Service, [21]. NLIS is now being prototyped in Bristol.

5.4 Interactivity

Virtual Reality tools have already been integrated with CBR, to provide a versatile graphical interface, [22]. Users of our system will be asked to engage with a simulation that embodies the concept of a city as a living organism, rather than a pictorial representation of the physical structure of the city. Thus we will be designing interactivity between user and simulation with respect to the particular type of engagement expected, [23].

6 Conclusion

In our review of city models it appears that whilst work still continues on existing analytical models, most new models tend to be of the graphical type. It could be argued that this tendency is driven by interest in Virtual Reality technology. However, apart from opening up models to a wider public, VR by itself does little "to promote urban development along a sustainable path" (the aim of the Leeds model). We agree with the aims of those building the Leeds and Cardiff models but we see the need to explore other ways of realising these aims. While current analytical models have been, and will continue to be, of value in planning the future of cities, it is our assessment that they are hampered by outdated technology. They are typically a patchwork of software systems built up over many years. Often the software originally used could only support mechanistic modelling, thus precluding a truly holistic approach.

In planning to produce a new type of simulation we build on the experience of those who constructed earlier models, having the advantage of more sophisticated software tools. However it is a challenging task, but one that needs to be tackled as the potential benefits make it worth the effort.

References

1. HMSO (1995), *First Steps - Local Agenda 21 in Practice.* in Municipal Strategies for Sustainability proceedings of the Global Forum, Manchester 1994. HMSO London
2. Gilbert, R., Stevenson, D., Giradet, H., and Stren, R. (1996) *Making cities work: The role of Local Authorities in the Urban Environment,* Earthscan, London.
3. Mitchell, G. & Kupiszewska, D. (1996) *Quantifiable City Project,* Final report of EPSRC funded project, EPSRC UK
4. Jones, P., O'Sullivan, P., Bowman, N., & Tweed, C., (1997) *Development and Completion* of *the EEP model* a bid for UK EPSRC funding, unpublished
5. Richardson, V., (1997) *Visible Cities* in RIBA Connect, p10-13, November 1997, RIBA London,
6. Jakeman, A., Beck, M., McAleer, M. (eds) (1993) *Modelling Change in Environmental Systems,* Wiley, New York
7. Richardson, V., (1997) *Visible Cities* in RIBA Connect, p10-13, November 1997, RIBA London.
8. Macmillan, B, (1996) *Fun and Games: serious toys for city modelling in a GIS environment,* in Longley, P. & Batty, M. (eds) Spatial analysis: Modelling in a GIS environment, Pearson professional
9. Checkland, P. (1981) *Systems Thinking, Systems Practice,* Wiley
10. Polanyi, Michael, (1958) *Personal Knowledge* Routledge and Kegan
11. Eden, C., Jones, S., Sims, D., (1983) *Messing About in Problems* Pergamon Press, UK
12. Popper, K. (1974) *Conjectures and Refutations: The growth of Scientific Knowledge,* Routledge and Kegan Paul, London
13. Watson, I., & Marir, F., (1994) Case Based Reasoning: A Review, in *The Knowledge Engineering Review* vol. 9, no. 3,
14. Watson, I., (1997) *Applying Case Based Reasoning: Techniques for enterprise systems,* Morgan Kauffman
15. Schank & Reisbeck (1989 *Inside Case Based Reasoning* Lawrence Erlbaum
16. ATEQUE, (1994) *Identification of Actors Concerned with Environmental Quality of Buildings,* Technical Document No. 1., Paris, December 1994
17. Hamilton, A., Curwell, S. and Cooper, I., (1998) *Towards Sustainable Urban Development through Internet Mediated Collaboration,* in proceeding of ALPS III European Union Euroconference, University of Brussels (ULB), Charleroi, 29th September to 1st October, 1997 publication forthcoming
18. Breheny, M. (Ed.), (1992) *Sustainable Development & Urban Form,* Pion, London, UK.
19. Jenks, M., Burton, E & Williams, K.(Eds.), (1996) *The Compact City: a Sustainable Urban Fur-m?,* E & FN Spon, London, UK
20. Sykes, J., & Lane, A., (1996) *Protocols for standards measurement at terrestrial sites,* The Environmental Change network
21. HM Land registry, (1997) *National Land Information Service: Feasibility study, executive summary,* HM Land registry, London

22. Oliveira, L., Retik, A., & Watson, I., (1997) *Intelligent Visualisation as an interface for Case Based Reasoning,* proceedings of the VRSIG conference, Brunel University, November 1997
23. Hamilton, A., Silverside, J., Torrance, A., & Hann, H., (1995) Designing CBT - focusing on the issues in *Computer Assisted and Open Access Education,* eds Percival, F., Land, R., & Edgar-Nevill, D., proceedings of AETT conference Vol. XXVII pp 132-139 April 1994 Napier university, Edinburgh, Pub. Kogan Page

An Assessment and Optimization Model of Environmental Influence about City Construction Planning in China Three Gorges Reservoir Area

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Abstract
In China Three Gorges Reservoir Area, it is planned to migrate 1200,000 people and build 128 towns. For long-term development and duration, this paper presents a multiobjective planning model about city planning, taking account of environmental influence, avoiding some disasters such as flood, landslide, water pollution, etc and optimizing some objectives like afforestation , land protection, city planning function , and so on.
Keywords: city planning, environment, multiobjective, optimization.

1 Foreword

In China Three Gorges Reservoir Area, 19 towns and cities are involved in the inundated area. There are 846,200 people living in area under the submerged water level now, 1200,000 people to be migrated, 470,000 acres farmland and 1599 industrial and mining enterprises to be submerged and 128 cities and towns to be built. In order to build so much cities and towns, environmental influence must be taken into account and the optimum scheme satisfying environmental protection must be chosen one by one.

This paper presents a kind of guiding ideology and an assessment and optimization model of environmental influence about town planning in accordance with the above-mentioned situation.

2 Guiding Ideology

2.1 Objective

Migration is the successful and failing crux of the Three Gorges Reservoir. For long-term development and duration, the environmental influences on construction must be considered. The objective is that the construction works that have good environment, safety and reliability, convenience of production and life for the migrants is created.

2.2 Criterion

The character of these towns is at the foot of hills and beside rivers.

(1)Environmental protection

The environmental qualities that we need are (a) the good environmental conditions of people's working, residence and action. (b)the good ambient conditions of building's formation, exist, maintenance, protection. (c)the good environmental conditions of human existence and development.

Criterion 1: All the natural conditions being beneficial to the environmental qualities are necessary to be protected.

(2)Environmental improvement

Criterion 2: All the artificial behavior being favorable to creating, maintaining, improving the environmental qualities needs to be developed. One content in them is that projects are used to improve the environment. It's expense needs to be scheduled into the total expense of towns construction.

3 Assessment Model

3.1 Affecting factors

When town site is selected and schemes are compared, the following factors must be

taken account of.
(1)Geology: geology, earthquake landslide, mud rock flow
(2)Landform: geomorphy
(3)Climate: rainfall, wind, air temperature, atmosphere pollution
(4)Hydrometic: flood, water quality, ground water
(5)Afforestation: foresting, green space, garden
(6)Land: space area, land protection
(7)Traffic: road, water-transportation, railway cableway
(8)Culture and art: history, culture, custom, education P. E. , amusement
@Planning designing construction: planning technique, design technique, construction technique
(1 0)Water supply and sewerage
(11)Energy power: power source without pollution
(12)Food: production and supply of food
(13)Economy: industry, agriculture , tourist industry, etc.
(14)Sanitation: environmental sanitation, hospital, the prevention and cure of schistosomialsis and disaster of insects pest etc.

3.2 Assurance condition

It must be satisfied the assurance conditions, including avoiding and preventing landslide, earthquake, mud rock flow, flood inundation, atmospheric pollution, wind storm, schistosmiasis and so on, otherwise the scheme of the towns planning will be abolished.

3.3 Multiobjective

The objectives of scheme optimization include(1)town afforestation (2)land protection (3)culture and art (4)complete function of city planning (5)traffic modernization (6)developing on economy (7)total expense (8)construction period.

3.4 Objective function

The corresponding objectives functions include:

(1)Afforestation ratio: the ratio between the afforestation area and the land use area
(2)land protection ratio: the ratio between the water-and-soil conservation area in the range of influence on city environment and the range of that;
(3),(4),(5)are represented as excellent, good, medium, bad, worst;
(6)One year GNP (10,000 yuan);
(7)Total expense (10,000 yuan);
(8)Time (month).

The objective values for qualitative factors are determined by the following standards:

The value of excellent fetches a data between 80 and 100.
The value of good fetches a data between 60 and 79.

The value of medium fetches a data between 40 and 59.

The value of bad fetches a data between 20 and 39.

The value of worst fetches a data between 0 and 19.

The larger (1), (2), (3), (4), (5), (6) are, the better, and the smaller (7), (8) are, the better, 8 characteristic values are confirmed as the objective function values for the different schemes.

3.5 Multiobjective Optimization Model

Taking the assurance conditions as the restrained conditions, the multiobjective is optimized. It is more complicated and difficult than single-objective optimization.

$X(x_1 \sim x_n)$ represents the variables of a scheme. There are 8 objective functions: $f_1(x), \ldots, f_8(x)$

Optimizing the functions represent

$$\text{Max}\,[f_1(x), f_2(x), \ldots, f_6(x)] \tag{1}$$

$$\text{Min}\,[f_1(x), f_2(x)] \qquad x \in D \tag{2}$$

Satisfying each restrained condition represents

$$g_u(x) = 0 \qquad (u=1 \sim m) \tag{3}$$

If $f_1(x) \sim f_8(x)$, each single objectives reaches the optimum. $f_1^* \sim f_8^*$, and X^* is a ideal point.

$$F^* = (f_1^*, f_2^*, \ldots, f_8^*)^T$$

Applying the Fuzzy set theory, each objective function values at the ideal point is represented as the optimum membership function. The noninferior solution is

$$F_i = [\,\mu(f_{i1}),\ \mu(f_{i2}), \ldots,\ \mu(f_{i8})]^T$$

The noninferior solution of the closest ideal point F^* is the multiobjective optimum solution. The corresponding scheme is the multiobjective optimum scheme.

4 Membership Function

The objective function value of ideal point is taken as a optimum.

Definition 1: If the larger the objective function is , the better, the membership function of objective for excellent is defined by

$$\mu(f_{ij}) = \left[\frac{f_{ij} - \min(f_{ij})}{f_i^* - \min(f_{ij})}\right]^P \tag{4}$$

$$\min(f_{ij}) < f_{ij} < f_i^*$$

where i is a scheme numbering

j is a objective numbering

p is a index value and tests confirm that p is 0.8.

Definition 2: If the smaller the objective function is, the better, the membership function of objective for excellent is defined by

$$\mu_{(fij)} = \left[\frac{\max(f_{ij}) - f_{ij}}{\max(f_{ij}) - f_{i*}} \right]^p \quad (5)$$

$$f_{ij}^* < f_{ij} < \max(f_{ij})$$

where the symbols are idem.

5 Method of search

5.1 Search

F^* and F_i: are two Fuzzy subsets, $\mu(f_1^*)$ =I, the relative distance between F^* and F_i is $\delta(F^*, F_i)$

$$\delta(F^*, F_i^*) = \frac{1}{\sqrt{q}} \sqrt{\sum_{j=1}^{q} p_j \left[1 - \mu(f_{ij})\right]^2} \quad (6)$$

where p_i is the weight coefficient of the jth objective
q is the objective number
$\min \delta(F^*, F_i)$ is the optimum

It expresses the smallest distance between the corresponding scheme and the ideal point. The scheme is the multiobjective optimization scheme of environmental assessment about town planning.

5.2 Weight coefficient

P_j, the weight coefficient is defined by research.

P_j=*(0.17, 0.16, 0.11, 0.15, 0.09, 0.10, 0.15, 0.07)*

6 Summary

Practice indicates that it is feasible that the assurance conditions are taken as the restrained conditions to optimize multiobj ective, assess environmental influence, abolish the scheme being disadvantageous to environmental protection and chose the optimum scheme.

Acknowledgements

We express our thanks to Mr Fahlstedt, he gave us a chance to join in the discuss about construction and environment.

Transport environmental implications of buildings

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Abstract

This paper describes work conducted by Davis Langdon and Everest and BRE which led to the formation of the Transport Related Environmental Impacts from Buildings Project - TRIP, funded by the EC SAVE programme.

Environmental audits of British Council Headquarters offices in London and Manchester revealed the significance of transport energy compared to life cycle operational and embodied energy for the buildings. The transport energy and consequential emissions from 6 further offices were studied under sponsorship from the UK Department of the Environment. In particular, the benefits of comprehensive public transport in London and reducing the use of singly occupied cars for commuting are prominent.

These studies have not taken into account the local environmental impacts of noise, dust, vibration and subsidence damage, traffic congestion and visual impacts which are prominent in local planning policy.

The methodologies used for the transport assessments entailed self-completion staff questionnaire survey and data analysis. Operational energy results were obtained from energy bills over identical periods without (degree-day) normalisation for location. Life cycle embodied energy estimates were derived from a prototype estimator.

TRIP aims to produce 15 to 20 case studies of initiatives taken by organisations in the UK, France and Spain to reduce the transport related environmental impacts from their buildings. The range of initiatives found in the UK are outlined and include ones that; use IT and teleworking, adopt different working practices, move location, promote public transport, car sharing, cycling and walking. Preliminary results suggest that these can provide sound economic and welfare benefits as well as environmental ones and these features often provide a sound business case.

TRIP will also generate a series of benchmarks of transport energy and emissions from 30 buildings studied at the pilot stage to identify the most promising cases studies. The case studies will present these in the context of the buildings and organisations studied.

Keywords: Transport, Environment, Buildings, Energy

1. Introduction

This paper describes the work conducted by Davis Langdon and Everest and BRE which led to the formulation of the Transport Related Environmental Impacts from Buildings Project - TRIP, funded by the EC SAVE programme. This stemmed from an environmental audit of the British Council's Headquarters offices in London and Manchester in accordance with the Council's corporate environmental policy. Initially, it was sponsored by the British Council and then extended under sponsorship from the UK Department of the Environment.

The paper then outlines some preliminary findings from TRIP which aims to produce 15 to 20 case studies of initiatives taken by organisations in the UK, France and Spain to reduce the transport related environmental impacts from their buildings. It illustrates the range of initiatives that have been found and suggests that these can provide sound economic and welfare benefits as well as direct environmental ones. In this respect, the benefits span the range of issues implied by "Managing for Sustainability".

Personal transport accounts for 22% of national energy consumption in the UK. A large proportion of this is used for commuting. Overall, emissions due to personal transport are growing at 4% per year.

2. Origins of TRIP

2 1 British Council Headquarters Offices

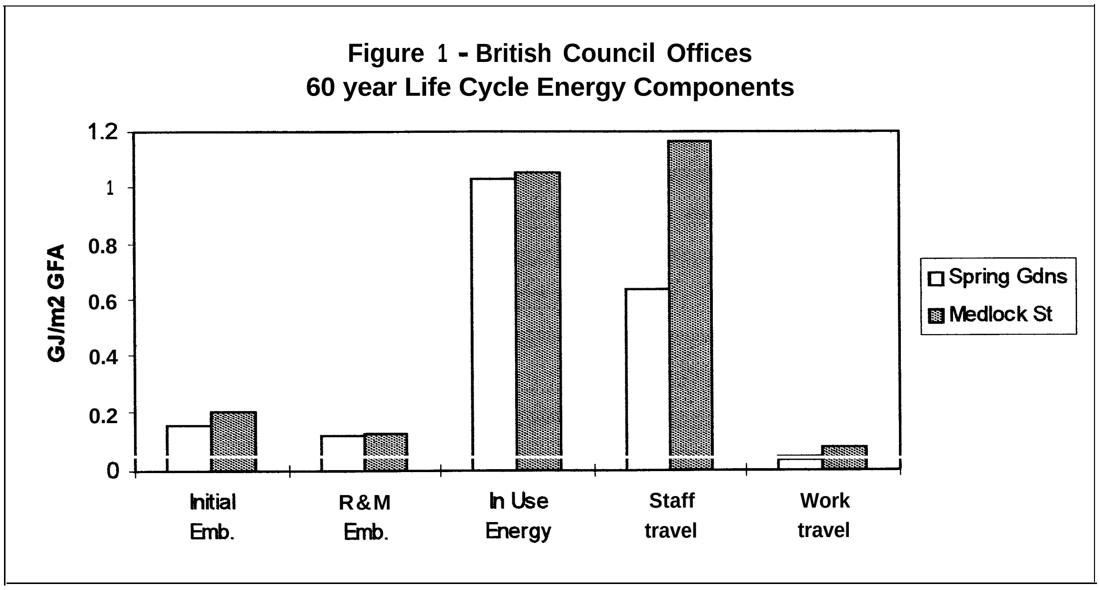
In 1994, the British Council launched a corporate environmental policy and strategy that placed emphasis on reducing the impacts arising from its buildings. Davis Langdon and Everest Energy and Environment Group were contracted to perform an environmental audit using BREAM 4/93 for existing offices. In addition, the Council wished to go beyond BREEAM in establishing the starting point from which they could monitor improvements in environmental performance. The emphasis of this work was on the Councils portfolio of property and how it was being utilised and not just the buildings in isolation. Hence, the Council were keen to explore the implications of repair and maintenance and transport and location.

The Council wished to start by investigating its two large headquarters buildings, one in Spring Gardens in the centre of London and the second at Medlock Street in Manchester. The London office is a 1970s prestige air-conditioned building in the heart of London between Trafalgar Square and the Mall. It is well served by public transport and has no car parking provision even for the most senior staff. The Manchester office was a late 1980s atrium building near to the centre of Manchester, built on a former contaminated land site. Although the site was reasonablly well served by public transport, much of the site had been capped with concrete and turned into car parking.

The repair and maintenance issues were investigated in terms of embodied energy for the buildings when built and then subsequently for their repair and maintenance over the assumed 60 year lives for the two buildings. The Council and their contractors had kept meticulous records, which facilitated the analysis.

The transport implications were investigated by means of a simple self-completion questionnaire survey for staff at the two offices. To encourage a good response, this was combined with a competition to win several bottles of champagne. The results were collected in just one day at each office. At both offices, a 10% response rate was achieved. This is a typical rate of response to self-completion surveys which are not chased. However, since only 50% of Council staff are typically in the office on any one day, there was, in effect, a 20% response rate by staff present, which is generally considered to be good. In all, 73 questionnaires were received from the London office and 56 from the Manchester office.

Figure 1 shows all of the results on a common scale of GJ/m^2 of floorspace for the two offices. The energy consumption is presented in delivered energy terms throughout.

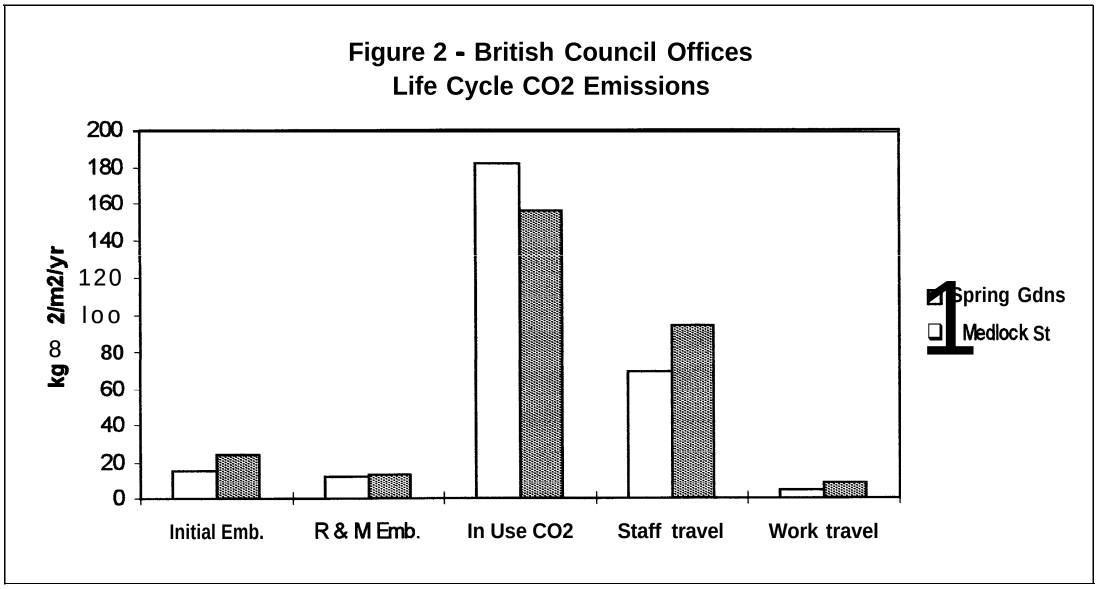


The results show that the embodied energy components for the two offices are similar, and relatively small compared with those for operational energy (heating, cooling, ventilation, lighting, power, catering etc.). The energy attributable to maintenance was particularly low (it can often be double these levels), a testament to the diligence of the Council in its maintenance procedures.

The operational energy consumption for the two buildings was almost the same. (Densities of occupancy were also similar hence the results are similar if expressed per occupant).

The most marked difference was that due to the energy used in commuter transport. Although staff in the London office typically travelled longer distances, their energy consumption overall was half that of commuters to the Manchester office. Scrutiny of the results confirmed that the crucial difference was the proportion of commuters travelling in cars with just one occupant.

Figure 2 shows the results expressed in terms of CO_2 emissions. Although similar in trend, the differences are smaller. This is because public transport in London consumes a greater proportion of grid electricity mostly from coal fired power stations (although the proportion is declining in favour of gas and other sources).



These results were considered to be highly significant because, at the time, benefits were being claimed for relocation outside of city centres with their associated pollution. Savings in energy consumption were anticipated avoiding or minimising the use of air conditioning. These results, however, reveal that this strategy can well result in extensive use of private cars for commuting. If, these cars are mostly singly occupied then net increases in life cycle energy consumption are likely.

2 2 Other Offices

In order to check that these results were representative, a further 2 British Council offices and 4 Davis Langdon & Everest (DL&E) offices were investigated using the same technique, but focusing only on the commuter transport issue. British Council Regional offices at Cardiff and Edinburgh and DL&E offices at London, Manchester, Cambridge and Liverpool were investigated.

Figure 3 shows the energy consumed in commuting for all eight buildings, together with the proportion of car transporation. Figure 4 shows the equivalent average transport distances for those responding to the questionnaires.

Figure 3 - Commuting Energy

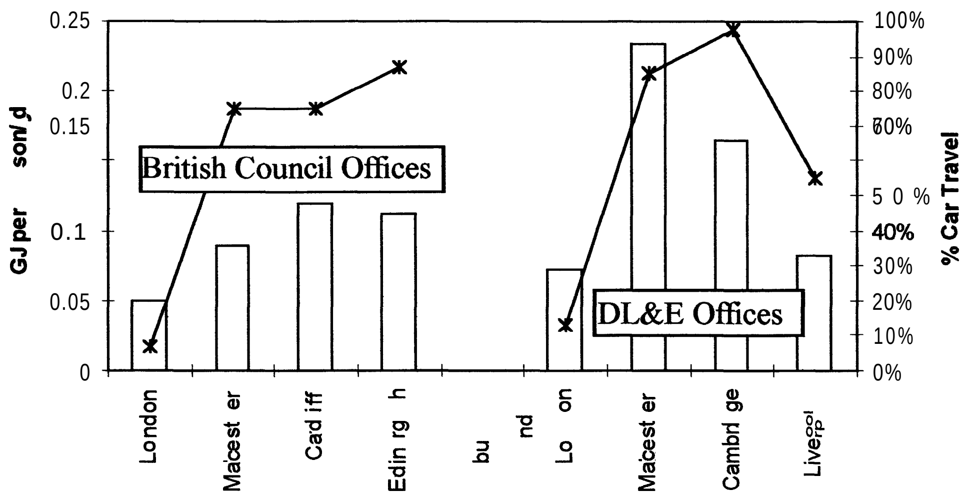


Figure 4 - Commuting Distance

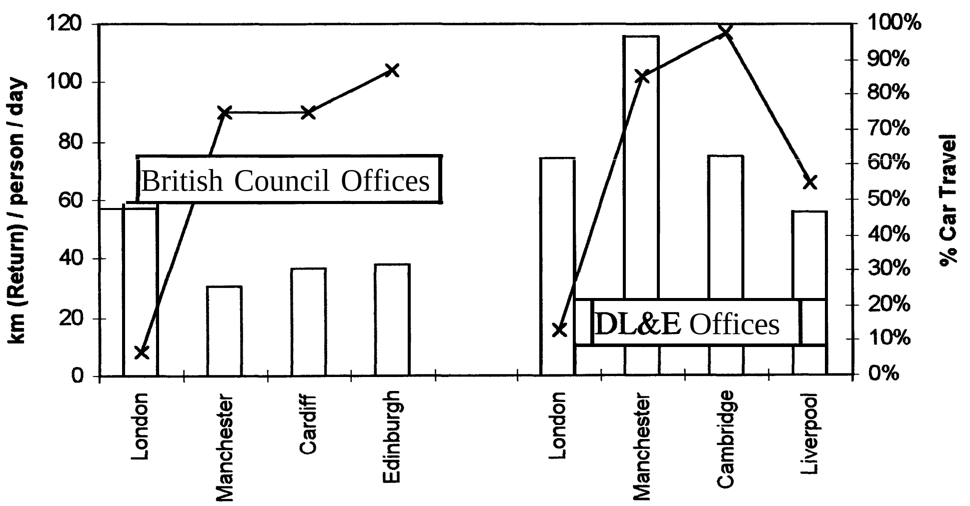


Figure 4 - Commuting Distance (repeated)

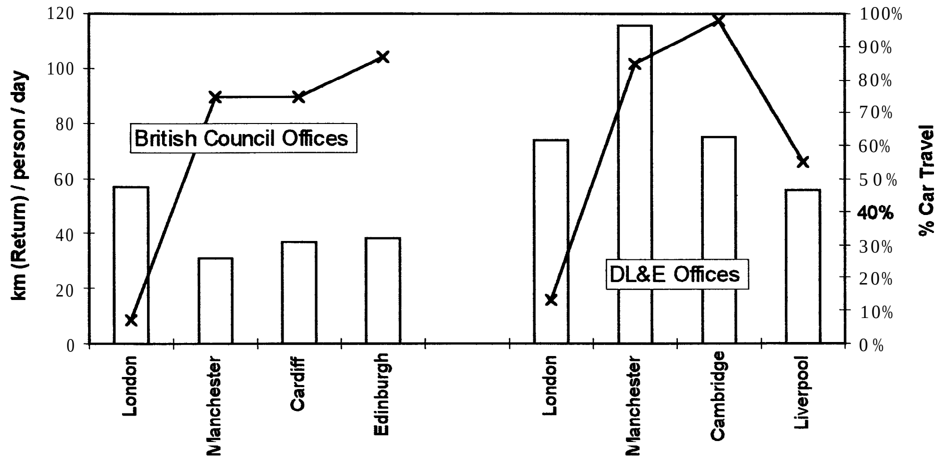


Figure 5 - Commuting CO2

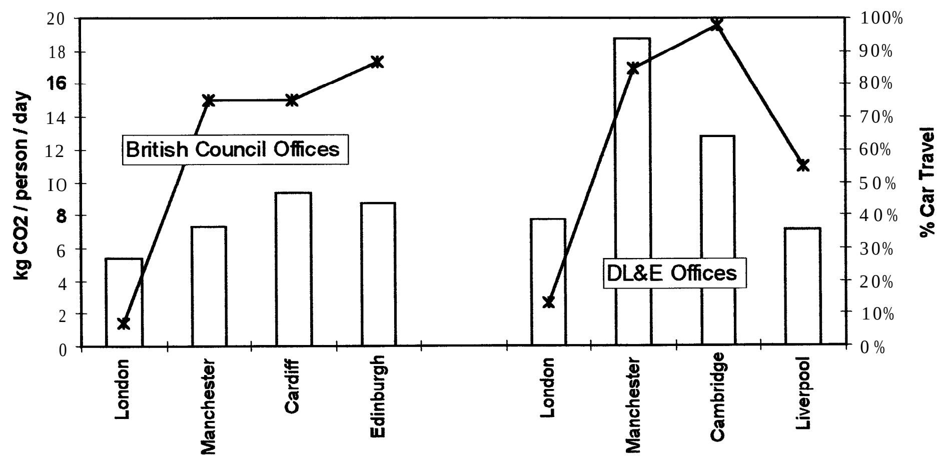


Figure 6 - Commuting NOx

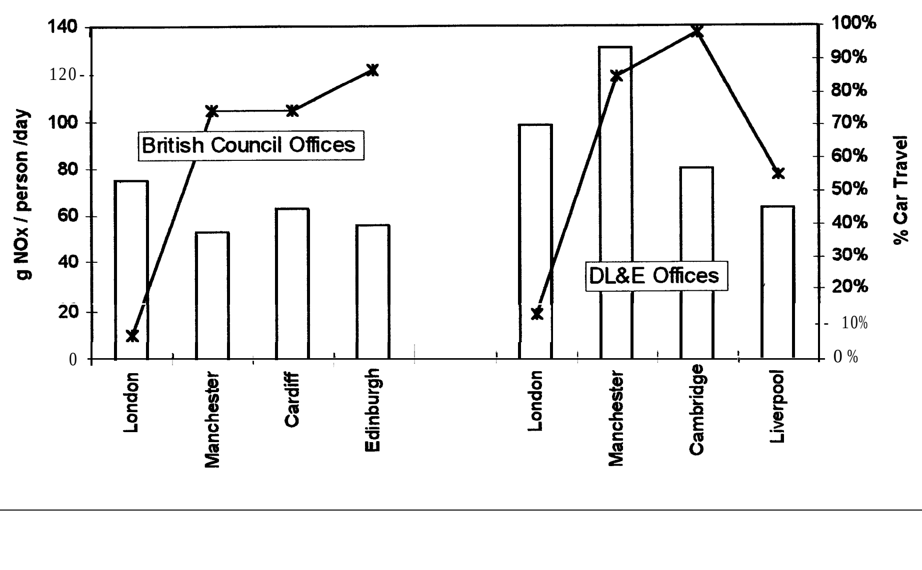


Figure 7 - Commuting VOC's

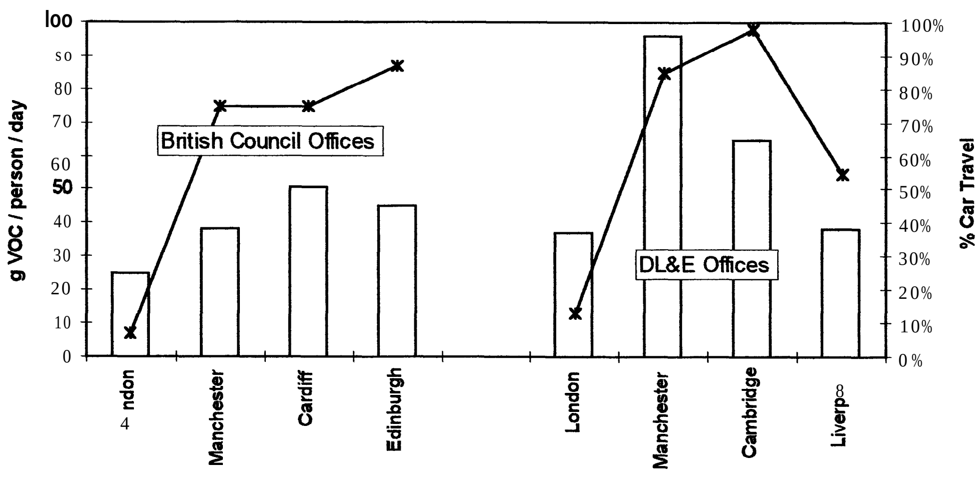


Figure 8 -Commuting CO

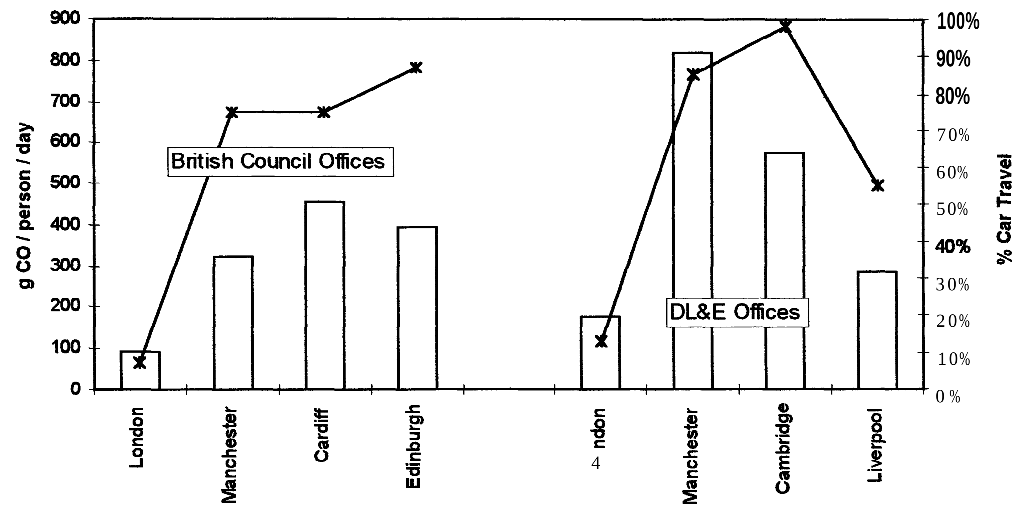
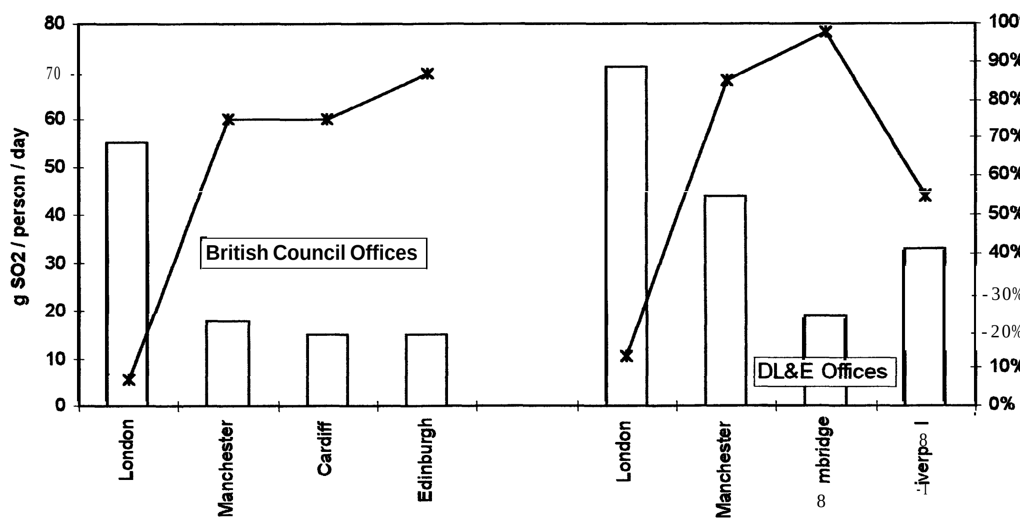


Figure 9 -Commuting SO2



Figures 6 and 9 show the emissions of gases that are acidic and contribute to the formation of acid rain. This can be transported over long distances and deposits especially in areas of high precipitation. Figure 9 in particular reveals that using public transport in London releases more SO_2 than commuting to the other sites even where singly occupied cars are the main mode of transport. This arises because of the SO_2 emissions from electricity production.

Figure 8 shows the carbon monoxide emissions from commuting to the different offices. Carbon monoxide is toxic to humans and animals. These results show that minimising car travel makes a major contribution to reducing this category of emission.

3 Progress of TRIP - Transport Implications from Buildings

To-date, this project has identified over 25 potential case studies in the UK across a wide range of buildings and types of organisation (see examples in Table 1). Offices predominate within the sample. The current phase of the project entails reviewing existing data about the building(s) and initiatives taken. The aims of this pilot phase are to define the starting point or reference case, to collate basic data and to determine the likely extent of potential energy savings and environmental impact reductions. The best 15-20 case studies will be evaluated in more detail using questionnaire surveys and energy audit studies-

Table 1 - Potential TRIP Case Studies in the UK

Organisation	**Nature of business**	**Location**
Argent Plc	Developers	London / B'ham
Hertfordshire C.C	County Council	Hertfordshire
Hobart Still	Manufacturers	London
Nat West Properties	Property Investors	Bristol
The Boots Company	Pharmaceutical / Retail	Nottingham
BT Workstyle	Communications	London
Hertfordshire University	University	Hertfordshire
British Airports Authority	Airport Authority	London
Oaklands College	Higher education college	Hertfordshire
Notts. Trent University	University	Nottingham
Hunting Gate Construction	Property mgt/development	Hertfordshire
Oxford Brookes University	University	Oxford
Nottinghamshire C.C	County Council	Nottingham
Surrey County Council	County Council	Surrey
Dr S. Roaf s House	Private, sustainable house	Oxford

Ideally case studies will show economic benefits to business or individuals, personal welfare and quality of life benefits to the occupiers as well as environmental benefits. These can in turn manifest in improved business performance both directly from reduced costs and improved workforce productivity and indirectly by demonstrating reduced environmental impacts from business operations.

Although no firm results from the study are yet available, the indications are that energy and monetary savings and welfare benefits to staff can be achieved, illustrated by:

- one organisation recorded a 13% reduction in car use by introducing flexible working hours with other measures.
- through a car sharing database and a bus service, one company forecasts a 10% reduction in commuter traffic by 2000, with a further 10% reduction targetted by 2005.
- a local authority plans to reduce singly occupied car travel to its main office sites by 30% by 1999, through the implementation of a commuter plan.
- for another organisation, incentives to use public transport have resulted in a 25 % increase in patronage on a number of bus routes, in the first 18 months of implementation.
- an educational institution offered free travel on city buses to staff for a week and recorded a 45 % increase in usage from staff living within the conurbation.
- One organisation is reducing the number of staff in a city centre location by 28 % (for financial reasons) and relocating them at telecentres at the periphery.

4 Conclusions

- The studies carried out at British Council and DL&E offices have examined the environmental consequences of transport and buildings only from an energy, resource and emissions standpoint. They have not taken into account the local environmental impacts of noise, dust, vibration and subsidence damage, traffic congestion and transport infrastructure visual impacts which are highlighted in local planning policies.

- The transport energy and environmental implications of buildings appear to be very significant compared with those for the construction and operation of buildings alone. Decisions made without taking account of transport energy use may result in sub-optimal consequences for the environment.

- Climate change and toxic pollution impacts are worse in buildings which encourage the use of private cars. Acid rain consequences are though, better in buildings that encourage the use of private cars by comparison with commuting to London on electric trains which use a large proportion of electricity from coal.

- Planners, construction professionals, buildings and business decision makers can therefore be highly influential in reducing the transport related environmental implications of buildings.

- As well as the environmental benefits, aconomic and social benefits may be obtained from initiatives that reduce the transport implications of buildings.

- The EC SAVE TRIP project will produce a portfolio of case studies to illustrate successful initiatives. The project will also produce benchmarks of performance for the transport-related environmental implications of buildings.

5 References

For data to enable energy and emissions to be calculated:

1. Transport Statistics of Great Britain 1978-1988, The Department of Transport HMSO London., September 1989
2. Personal communication Bruce Oelman - The Department of Transport - October 1994

Other relevant papers:

3. Howard N and Roberts P - Environmental Comparisons, The Architects Journal, 21 September 1995
4. Whitelegg J - Driven to Shop - Transport Intensity and the Environment, s.a.f.e alliance, London
5. World Transport Policy & Practice - Vol. 1 No. 1, MCCB University Press, 1995

Sustainability & regional planning: Barcelona's area case study

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Abstract
In this paper the authors have the proposite to study the sustainable concepts which should be priorities in the territorial planning of the Barcelona Metropolitan Area. Underlying the economics and social characteristics of the region studied and the tools of the territorial policy which are available for authorities to achieve the territorial arranging.

The methodology used is based on the general patterns to achieve the sustainable development like as Agenda 21, V Action Program in European view and eco-urban model. The working method applied is going to make up a selection of the most important objectives within local characteristics of AMB. With they, we are going to get a indicators that will be used in strategies configuration with sustainable objectives.

In this paper, we are studied the actual trends and the possible configuration of sustainable strategies.

The authors have considered the usual topics in the regional planning within this area, like as net services, mobility versus accessibility, the urban wastes, energy saving in building, the water and draining, protection of atmosphere, natural parks and humids areas.

The dynamic demographic and sustainability within the territorial planning should dominate the holistic concept in realign of the actual and new occupations, as a consequence of the expansion and dispersion of people in a urban continue, prolongation from the actual Barcelona conurbation to peripheries limits of the region.

The policies of nature protection (forest, fires, drought, erosion, water, flora and fauna) and the protection of the atmosphere should dominate against other actuation which looks like more urgency for the quality life of people.
Keywords: sustainable strategies in regional planning, sustainability and regional planning, sustainability in Barcelona's area,

1 Introduction to Barcelona Metropolitan Area

The metropolitan area of Barcelona is allocated in the north-occidental Mediterranean shore and constitutes the most important economic area in Catalonia, one of the three historical nationalities of Spain, with own government and parliament and also autonomous administration.

Catalonia is a Mediterranean country, but moreover is a European country and in the European union is shaped within the limits of euroregion, it constituted by Catalonia, Midi-Pyrinnes, and Llanguedoc-Rosello.

Catalonia is a mountainous country and its territory is raising from warm plane of Mediterranean coast to Pyrenees Mountains. This geomorphology give a lack of planes territories, with slope lower than 20%, and is essential because population, which is constituted by 6 millions, is allocated basically in planes areas of Mediterranean coast.

AMB is constituted by 7 historical counties with 162 towns and take up a surface with 3325 Km^2 and 4.2 millions of residents that represents the 70% of Catalonia totally people. The density is about 1.3 17 residents per Km^2 and constitute the double of the more urbanisation European regions. The most important urban area is the Conurbation of Barcelona, and it is integrated by 9 towns, with 168 Km^2 of surface and with 2.5 millions of residents, which are concentrated in a small territory, because its density is 14.700 residents per Km^2, higher than the density in the European metropolitan areas.

This density is reflected in the model of territorial occupation and it is, mainly, determined by Conurbation of Barcelona (CB) with its principal focus in the city of Barcelona. Constituting the most important phenomenon in AMB. This urban character determines all the effects over the environmental field.

The boundaries of Conurbation of Barcelona are natural limits constituted by Mediterranean coast in south, Collserola mountains in north, Llobregat river in west and Bessos river in east.

2 Territorial planning in AMB

The territorial policy was born from Territorial General Plan of Catalonia (PTG), on 1983. This plan was born to define the territorial equilibrium and to be the action shape.

The objectives, programs and facts realised during the last years in AMB has been oriented through one referent pattern: PTG.

The metropolitan territorial plan of Barcelona was done in 1987 to find the general objectives within PTC about soil regulation.

The Infrastructures plan of State (1993) determines a different kind of actions until 2007, which the most important are destined in Llobregat river. This activities want to alter the course of this river, to build one logistic area, to extend the Barcelona airport and, finally, to build the infrastructure of the T.A.V.

3 Environmental parameters of sustainable planning in Barcelona Metropolitan Area

The general patterns to achieve the sustainable development are Agenda 2 1, V Action Program in European view and eco-urban model. Work method to apply is going to make up a selection of the most important objectives within locals characteristics of AMB, and with it, to get a indicators that will be used in strategies configuration with sustainable objectives.

Section II of Agenda 21, destined to management and maintain the resources development, it looks the territory as a essential part where is possible developed the sustainable objectives, such as: resources management, avoid the deforestation, drought and blighting, sustainable agriculture, the sea protection, etc.

The V Action Program, in territorial order field, has a indirect effect because is referred to nature protection and biological diversity, environmental quality, based on the Green Book about environment, and also, protect the tourist impact in the offshore.

Eco-urban Model use own elements of the city and it is built from European model which keeps a central position in metropolitan urban.

4 Local limitations within sustainable patterns

The method used in regional planning about sustainable parameters is mainly based on Section II of Agenda , but also in the rest of the section.

The proposite of this paper is not a redact about a Local Agenda 21 for AMB, because the unique objective is introduce and underline the criterions for the selection of the themes which are prioritaries by the autors and should be implemented in sequential advance than the other topics.

A brief reflection about geophysics environment in AMB show as the region participates in general attributes of Spain, and also, in any of Catalonia. Spain has, in European category, a climate relatively warm and its population is concentrated in urban areas. There are so different characteristics through Spanish territory referent about climate, environmental norms and territorial regulations. Catalonia, for instance, has more laws and regulations than others regions in Spain about flora, soil and fauna which represents a advantage situation in sustainable indicators. However, Catalonia is the most industrialisation region in Spain and this industry is centralised in RMB, and it allows a particular characteristics when are determined the main objectives in social and economic sustainable development in the region.

On the territory planning of AMB would be desirable a holistic treatment of these territories that include different focuses and activities with integration, and therefore, avoid sectors more important than others. However, the few extension of AMB, is a limitation, and also, sometimes avoid a totally study and knowledge about this concept.

5 Sustainable strategies and actual trends

The last town-planning activities to prepare the Olympic Games on 1992 found a different and traditional type of problems associated within AMB, and specially in its CB.

These problems were solved by authorities used sustainable criterions, but more important was that a culture about territorial planning in quality life was created.

The result of this new policy will be explained in the following points.

5.1 Services nets

Actually, the AMB authorities include, in the territorial planning, the services structure which exchange matter, energy and information. It requires to build a nets that satisfying the transport through the knowledge of the future demand despite of in the territorial planning is difficult to know the future demand and tendencies that will be introduced on 2026.

Actual studies show as the last years, the services sectors had built the nets without co-ordination between sectors, avoiding minimise the occupation in the territory. The lack of co-ordination between sectors, and also, the few interest showed by authorities and politics about it, produces ecological, social and economics problems caused by the extensive occupation in the territory.

Services net reorganisation, represents an important expenditure because a bad planning was applied. In Barcelona, during the last 30 years, each year are opened 20.000 canalisation services. The investment of 180.000 millions of pesetas to build its ring ways, 30.000 millions of those were spent in services reorganisation because were affected by this fact.

The electric lines (more than 66 kV) have a surface of 10.000 Ha. in AMB, and is the same that the surface of Barcelona town. The whole of transport and communication nets occupy 25.000 Ha. within the region, when has 50.000 Ha. of urban soil.

Telecommunications nets must to be replaced every 15 year, energies net every 20 or 25 year and water channels every 30 or 35 year. To reduce urban environmental effect of these actuations, AMB authorities have proposed to build a social ways which will constitute the metropolitan avenue.

5.2 Transport: Mobility versus accessibility

A sustainable policy of transport in AMB must be oriented with equilibrium between cost-revenue analysis of private transport and cost-revenue analysis of public transport. This fact means that the private costs must be internalised (tax over combustible, tax by use of public ways, tax over station-places, etc.) and also the public revenues (advantages over public transport, increase the net, etc.).

The region needs a strategy to reduce the movement in it through a accessibility promotion as a central concept within a sustainable mobility policy. To promote the accessibility means: reduce the necessity and longitude in movements, reduce the inefficient car utility and promote alternatives transport systems. This policy of sustainable mobility needs urban actions, deep changes in town-planning, new technologies and changes in citizens actuations.

In town-planning model, the urban developments should introduce the different utilities and activities in holistic perspective . The new working methods derived from telecommunications may reduce the actual mobility.

Actual mobility treats in AMB are realised without sustainable mobility. For instance, the parameter of mobility raise on 1.2 times the PIB increment, and this fact has created a increment of travels between center-periphery and vice-versa , with raise of cars to CB, more use the private car against the public services, increases the urban congestion, etc.

To avoid these problems, and using the Agenda 21 and V action program models, authorities have introduced a Transport plan (PIT) between 1993 and 2005, and with it create a global transport system based on public services.

Will be important innovations with alternatives combustibles and with transport fashion, the new streetcar is an example.

5.3 The Urban wastes

In these moments the management policies in urban wastes in AMB is carry out by a unique authority, (EMSHTR) which regulates the metropolitan program in waste management. This program find to achieve a more sustainable development than the actual of it, with 10 years of place.

Program objectives include European norms and county legislation which maintain the sustainable development attributes.

In this program will be a important raise of services costs because will appear, step by step, rubbish dump and incinerators to preserve the environmental norms. The volume of this investment is about 47.000 millions of pesetas. This investment will be pay through FEDER and Financial Resources of Cohesion from Europe, County Government and different Towns.

To avoid uncontrollable actions with wastes will be apply a string between plane area and mountain area.

5.4 Saving energy and housing

In Spain, the saving energy measuring never has been successful within authorities and enterprises mentality because, on one hand, there are cheaper energy and on the other hand the climate is relatively warm.

Catalonia is one of the European countries where the industrial activities have a so important weigh within its economy. This fact determined that government five years ago begun renovation industrial programs in according to sustainable development. Thus, very much actions has been centred in optimise the energy use, to reduce the expenditure, and also, to achieve diversification and introduce news technologies in the firms.

The saving in the energetic efficiency field has been more than 275.000 tep/year, and the technology application in new generation has allowed a electric power of 500 MW in 1996.

In renewable energy field the programs and projects are frequents, and now , 7.5% of primary energy consume is cover by renewable energies.

In the building sector, the activities to promote energetic saving are not accept by partners and builders; the indirect revenue available through the investment in termic isolation is not attractive for theirs.

On the other hand, authorities promote technologies in this field. RMB has warm climate, the Mediterranean climate, characterised by short and benign winters, few rain, and with a summer period dry and hot

AMB has been the first region in Spain to substitute the traditional heating system based on coal, and after on gas-oil, by gas. This policy is carry out through the gas arrived from Algiers to Barcelona harbour.

This fact, has allowed measures to combat emissions of harmful gases, provoked by open fireplaces without filters.

Actually, the main calorific energy source on domestic and industrial uses is the natural gas. The last action to increase the consume of natural gas has been the gas pipeline built between Magrib and Europe.

5.5 Water and draining

The water in AMB has been a important objective by government and society, today the region has solved this necessity as consequence of the infrastructures built and the water management policy from the Catalonia rivers. The new necessities will be solved by water from France and other areas of Spain.

Actual draining policy of contaminated rivers, programs to build purifying plant, policies for saving water, eco-taxes, etc. keeps AMB as one of the most important areas in water management in Spain.

5.6 Climatic change

The programs in atmospheric protection to achieve a sustainable development are subsidiaries from the industrial policy in Spain. AMB participates in the increment of the emissions of harmful gases with 17% until 2010.

The industrial growth in the region is 115 Ha by year of industrial soil. This fact means that the region will increase the emissions of gases caused by direct incidence, transport and electric generation, or indirect incidence by consume effect.

In this question, AMB is not going to have sustainability, and authorities will must reinforce the programs with limitations and controls in the Region.

5.7 Natural parks and humid areas

Collserola Mountains constitutes within AMB its natural park. This park is constituted by Mediterranean trees (oaks, holm oaks and beeches,) which are not economically worked but have a town-planning pression. The forest fire is the most important problem. The policy is oriented to sustainable development, and the plans seek the environmental revenue, thus, the forest is used as a genetic reserve to maintain and create soil protected against erosion.

The small lakes in the south of AMB, constitute a special area of birds protection and is situated in the Llobregat river. The infrastructures which are building there, alter the curse of the river, the airport and harbour, can affect the European norms and are being studied now by one European commission.

6 Conclusions

With the study of sustainable and territorial planning of AMB we can talk about different conclusions. AMB is a region with extension limited, high density of population and with a industrial periphery that presents coast and forest attributes with warm and dry climate. This climate allows industrial, economic and social activities with European characteristics.

The infrastructures to be realized in the next future in this area could be irreversible for the territory and it advises to actuate with special care and attention to the ambiental protection.

The demographic dynamics and sustainability within the territorial planning should dominate the holistic concept in realign of the actual and new occupations, as a consequence of the expansion and dispersion of people in a urban continue, prolongation from the actual Barcelona conurbation to peripheries limits of the region.

The policies of nature protection (forest, fires, drought, erosion, water, flora and fauna), and the protection of the atmosphere should dominate against other actuations which looks like more urgency for the quality life of people.

7 References

1. Agencia del Medio Ambiente de la Comunidad de Madrid (1995). *Madrid 21, estrategia para el desarrollo sostenible en la Comunidad de Madrid.*
2. Lorente, J. (1995) *Ozó i clima: repercussions dels canvis antropogénics de concentracid de l'ozó*, U.B, Bull. Soc. Cat. Ciènc., Vol. XV, Numero 1, pp. 143-147.
3. Martin Vide, J. (1995) *La Pluviometría en Catalunya*, U.B, Bull. Soc. Cat. Ciènc.,Vol. XV, Numero 1, pp. 135-141.
4. Petrella, R. (1992) *Demà, les ciutats europees. Preguntes i respostes*, Quaderns de Tecnologia, pp. 28-39, april 1992.
5. Serratosa, A. (1997) *Les infrastructures i les xarxes de telecomunicacions emergents,* course in Planificacio i Sostenibilitat. Paràmetres ambientals d'ordenació del territori. XI Universitat Tecnica d'Estiu de Catalunya. Sitges.

Difficulties into application of the sustainable concepts on construction in Spain

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Abstract
The main aim of this paper is introduce several aspects related with sustainable construction, in order to demonstrate the different points of view about focused actions in sustainability construction depending on the geographic and cultural perceptions.

Another aim is promote a general discussion about the different senses of the construction sector depending on the importance and local influence in each country and the difficulties for the administration to introduce, regulate and apply the general concepts that actually are developing in the international context.

This paper is based on a project developed by our Department focused in the evaluation of the problems and inconvenients on the application of the sustainable construction concepts in our specific country.

This project was divided in a few parts, depending on the subject of study. In this paper we will show the four mean parts of this work.

Concretely we will introduce the state of the life-cycle analysis in Spanish construction, the situation of the environmental impact studies of the building and materials, the construction waste management and the energy aspects of the construction process and the energy buildings efficiency.

All studies was made over several different points of view: designers, public and official institutions, clients, users, general people, builders and contractors, suppliers of equipments, producers of construction materials, etc, and in this paper we emphasize this most relevant aspects of each point of view.

In addition to this general ideas, we are going to comment the mean problems detected in each branch of the project under the different points of view. In case that we would have developed new tools to improve this applicability, we will comment these.

In the last part of this paper, we show a conclusions resuming the mean barriers to introduction of the sustainable concepts in construction discovered during the realisation of this project.
Keywords: barriers to application of practical concepts on sustainable construction, difficulties in practical application of sustainable construction, geographic points of view, problems in application of sustainability concepts.

1 Introduction

We accept that in general sustainable construction must be a respectful with the environment, with sustainable utilisation of energy (in Spain with special focus in solar energy) and taking in account the importance of attention to environmental impact that origin in some construction materials.

This work have an aim to check the applicability and feasibility of the concepts on sustainable construction in a European and Mediterranean country, with their own particular characteristics.

We have been working in the two last years with different approximations and ideas, and we have studied what subjects are more important in our country. The study is based in the perceptions of different involved parts: designers, public and official institutions, clients, users, general people, builders and contractors, suppliers of equipments, producers of construction materials, etc.

We are conscient that in this paper we don't have had in account the quality aspects directly related with sustainability, the performance of the buildings directly related with sustainability, and others basic aspects, but we only want to remark the different perceptions of the different parts involved in the construction process and the different points of view depending on the geographic and cultural characteristics of the country.

We want to introduce the idea that the final sustainable construction concepts should be developed from an cross-cultural point of view and taking in account the different regional and national perceptions and senses.

2 Study methodologies, current results and discussion

In sustainable construction, the author's origin (geographic origin and professional origin) determines the contribution made for each particular idea or model

According to this influence, we studied the adequacy of the different :international ideas and recommendations from our particular perception like engineers from an European and Mediterranean country.

So, we didn't study the implications looking for the way to change completely all our construction methods and ideas.

The study was made looking for the better ways to improve the environmental implications of the construction works.

We divided the study in five mean parts:

1. life-cycle analysis of materials and buildings
2. environmental impact of the building and the materials
3. construction waste management
4. energy perspectives of the construction process and energy efficiency in buildings

Following we introduce some ideas about each subject and make the discussion about the obtained results and main difficulties detected by the authors during the realisation of the general study.

2.1 Life cycle analysis

The aim of this methods are developing new products, or adapt the existing .products, from an environmental point of view.

Obviously the analysis must include the total life of the product, element or building: from the raw material extraction; the production of elements and their envelopes; the installation of the product; the use of this product and their final removal [1].

The own state of the art related with this aspect implies that would be necessary to evaluate the different life-cycle depending on the particular element or product.

The cultural and historical differences between countries provoke that the most used products in one country would be different than in other nearly country. For instance the evaluation of the ceramic materials life-cycle (bricks or ceramic covering) is a big priority in our country more than in other countries.

Another problems are the different ways to produce the materials, depending on the production technologies. Sometimes this industry is regionally important and is social and politically difficult to influence in it.

We must add to this scenario that this science is growing up from the union of several practical experiences, more than a general and structured strategy.

In the next future is necessary:

- obtain the support of the government in all the related aspects: information, control, regulations, economic incentives, R+D promotion, . . .
- convince to population on the importance of the use of well appraised products.
- introduce this concepts into client and designer strategy and into builder firms management strategy.

2.2 Environmental impact of the buildings and materials

The construction process must be considered like an another pollutant industrial process.

The main aspects are totally commons between construction process and others: raw materials extraction, installation elements, energy consumption and waste generation.

Although, from people point of view in our society, the construction process isn't considered extremely pollutant (less than textiles, metallurgic or another processes) and the environmental impact usually is falsely associated only with visual impact.

Under these general considerations, we can define the following mean single objectives under their associate whole objectives:

- mean single objectives: energy consumption reduction, raw materials consumption reduction, materials reprocessing.. .
- associate whole objectives: decrease CO_2 emission, preserve natural resources,. . .

Some international strategies of reduction of environmental impact could be:

- the use of reprocessed materials to make concrete.
- the general reprocessing of materials and construction waste [2].
- the reprocessing of construction waste from pulled down old buildings [3].
- the reduction of the environmental impact due to materials transport [4].

In this field, actually the designer could be able to introduce some sustainable concepts in the project stage only if the client accept it, due to we don't have regulations related with this subjects.

In relation to the environmental impact of the buildings and materials, the most relevant problems is that the designer would be able to know and master the sustainable concepts related with construction, and at the moment this isn't successful.

Another important subject is to provide effective evidences to the client to obtain the approval of the financial aspects and implications on use and introduction of these points of view.

In respect to the regulations of the construction process, the recent initiatives are in order to increase the health and safety in it.

In the next future, will be necessary to include the environmental aspects in the construction regulations, but this aspect at the moment is in the first stage of their development.

2.3 Construction waste management

In Spain, on 1996 was produced around 20 Kg of waste by person and day, and the 7 per cent of this weight are construction waste [5].

Actually the Spanish strategy in this field seems to be the minimisation of the waste construction production, the promotion of the reprocessing works and the optimisation of the removal of construction waste don't able to be reprocessed.

Furthermore, the existing demolition companies have problems with the new strategies and their compatibility with the current workers, methods and equipments.

Another problem is the different level of waste treatment in the different Spanish regions. For instance, in Catalonia, from 1994-95 we have clear instructions and regulations to realise the pull down of the old buildings [6, 7].

In addition, the regulations force to make the deconstruction project, with the working process necessary to pull down the building, the process liabilities and the final utility for the waste construction.

The main problem actually is to make feasible this objectives with the current dumps and the hardly existing reprocessing plants.

2.4 The relations between buildings and energy.

Under this subject, we consider two different aspects. The first one is the *Energy perspectives of the construction process* and the second one is the *Energy efficiency in buildings.*

Following with this studies, we considered that *Energy in the construction process* involve the energy included (i) in raw materials extraction, (ii) in the elements production including (iii) the energy cost of transportation until the construction site and (iv) in the installation of equipments and components. The total energy involved in this three first points is over the 85 % of the total energy involved in construction process [8].

In Spain the total energy necessary to build a house is upper to the energy consumed during five years.

The solution, obviously isn't in the construction site management. The future trends must go on direction to reduce the energy consumption in the materials production processes.

In respect to the second one aspect, the main energy efficiency objective generally is to design the building with a low energy consumption and using the local climatic and soil conditions of the particular region where is placed the building.

In Spain, this aspect includes the study of the correct location and orientation, the relation with the surrounding vegetation and the natural lighting. Obviously all this subjects are extremely related with the building design and the project, and they are related with the capabilities of the designer.

We can mention initiatives to develop studies related with use of natural cooling and ventilation of buildings, passive heating and cooling systems, solar irradiation protection, etc.

The mean problem is the treatment of the solar influence in the buildings. In the Spanish regulations about thermal conditions, the solar response in buildings isn't adequately treated. So, is necessary by the designers extend the studies during the design stage in order to appraise the future energy consumption in the buildings.

Another big part of this subject are related with the building services: lighting, heating and cooling systems, ventilation, energy management, water supply, draining systems, . . .

The current technologies to use in aim to increase the energy efficiency of the building services are:

- advanced lighting components,
- building control systems,
- air-conditioning (heating-cooling) advanced controls,
- energy co-generation and energy conservation,
- central production and solar production of hot water,
- water-separation between rain water and sewages,
- reprocessing of non-drinking water,
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This field is one of the most well-develop actually in Spain, due to the attractive market perspectives for the companies involved in this subjects. The reason is that the energy is directly related to the monetary costs, so, the users are quite interested in the use of this new elements, and another reason is the increasing use of these systems (advanced efficient lighting and air-conditioning systems) in housing, that extend the market for these suppliers.

3 Conclusions

We have explained our perceptions about some sustainable construction concepts and their application in Spain. In order to promote a general discussion between different geographic and cross-cultural research teams, our conclusions will be write only like a resume of the mean problems detected during this study.

We want to emphasise in our particular point of view, promoted by our particular construction needs, and remark that we don't want to develop a closed study and conclusions, and we don't try to export this conclusions to other countries that are working in this subjects.

So, the main barriers and difficulties on implementation of sustainable construction in Spain are:

- lack of information in general about concepts, about the use of this concepts and about the use of this concepts by the professionals involved in the construction process.
- lack of training in technical schools about environmental and sustainable concepts and their use and application.
- lack of culture on sustainable concepts for the people in general.
- lack of responsibilities definition in the construction process from a environmental point of view.
- lack of legal aspects and regulations to promote the adoption of this concepts.
- the point of view too much conservative of this industry, with tendency to use traditional designs and construction methods.
- the benefits from sustainable construction are diffused by general people.
- the difficulties to evaluate and quantify the environmental impacts of buildings and materials.
- lack of financial incentives. In traditional financial appraisals the intangible benefits of sustainable construction aren't usually included.
- lack of general pedagogy about this subjects. In general, people thinks that sustainable buildings are stranges things.
- the green labelled of some products for marketing reasons more than for environmental conditions of these products.
- the non-existent information about environmental responses for the most usual used products of construction-
- the great opposite inertia to change the regulations in order to force to introduce the environmental and sustainable aspects inside the technical information supplied to the designers and professionals.

4 References

1. Moch, Y. (1996) *Impacte ambiental dels materials de construcció*. I Jomades sobre construccio i desenvolupament sostenible. Barcelona, 1996 May. (in Catalan).
2. Baldwin, *R. (1997) Sustainable Development and Environmental Assessment.* Proceedings on Second International Conference Buildings and the Environment, Paris, pp. 557-563.
3. Speare, R. S. (1995) Recycling of Structural Materials. *The Structural Engineer,* Vol. 73, No. 13.
4. *WWF* (1993) *The built environment sector.* Council for Environmental education, Department of Environment, De Monfort University, Leicester.
5. Elias, *X* (1996) *Valoritzacid i reutilitzacid de residus*. Master en Enginyeria Ambiental de l'Empresa. Barcelona. (in Catalan)

6. ITEC, (1995). Manual de desconstrucci6. Departament de Medi Ambient. Generalitat de Catalunya, Barcelona. (in Catalan)
7. ITEC, (1995). Aprofitament dels residus en la construcció. Departament de Medi Ambient, Generalitat de Catalunya, Barcelona. (in Catalan)
8. Connaughton, J. (1990) *Real Low-Energy Buildings*. RIBA, South West Region Conference, The Energy Challenge.

Fragile networks and robust gates - A view on managing for sustainability

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Abstract

As designers and specifiers of building products, architectural practices could be seen as important agents of change. Although a small proportion of architectural practices are leading the way through innovative design and the selection of new materials to achieve a sustainable goal, it has been argued that the majority of practices have been slow to change their behaviour, preferring to stick to well known design solutions and familiar products. This paper presents the findings of two separate but linked research programmes that sought to investigate how management techniques employed by architectural practices limit, and often conflict, with a desire to design for a greener environment. The research has highlighted some of the social and structural issues (often overlooked by the promoters of sustainable design) associated with the adoption of environmentally responsible ideals and practices, drawing on both diffusion of innovations and gatekeeping literature. The summaries of the research have indicated that the management systems employed by architectural practices in the form of both formal and informal gatekeeping systems limits specifiers' exposure to information about new building products. The newer the product to the practice, the greater its perceived risk and the greater the likelihood of it being rejected at formally established gates.

The architect is arguably the only player capable of providing the holistic view required to bring about quality and an ethical approach to sustainable construction, although on the evidence presented above it would appear that inertia to change is restricted through an attempt to manage risk, information overload and the effective use of staff time. Furthermore, the contribution to the specification process from other members of the temporary design team, such as the client, planner and contractor needs to be recognised and researched further since all of those involved in the selection of building products have a role to play in the quest for environmentally responsible building.

Keywords: Change agent, Diffusion of innovations, Environmentally responsible building, Gatekeepers, New product adoption, Risk management, Specification,

Introduction

For a conference concerned with building and the environment there is little need to repeat the well worn argument that something must be done to change the way in which we convert our relatively balanced natural environment into a relatively chaotic artificial one - fuelled through what Samuels [1] has called a lifestyle on the edge of chaos. The keyword here is 'balance' since the majority of literature concerned with the promotion of sustainable issues continues to be largely evangelical in nature and rarely based on examples of what is actually being done in practice [2] Furthermore, many firms are starting to claim through their marketing literature and mission statements that they are acting in an environmentally responsible manner, although research has found that such claims are exaggerated and their actions naive [3]. Indeed, the word 'sustainable', although in common usage is open to a wide variety of interpretations' for example it is used in the business and management field to refer to increasing nnarket segment, thus sustainable in this context has little to do with 'green issues'. Therefore the term 'environmentally responsible' is used in an attempt to convey the notion of individual responsibility for improving our environment, not merely sustaining it. So perhaps it is time to face the difficult questions and actually look at what is being done and how close (or far) we are from achieving some form of environmental balance.

If individuals within the building industry are to work towards environmentally responsible building, then all members of the building team will need to make a commitment, change their existing behaviour and start adopting new products, ideas and practices. But it is frequently argued that the pace of change in building is relatively slow, a phenomenon put down to the fact that people involved in building are uncomfortable with change. To a certain extent it may be true that there is resistance to the adoption of new technologies in the building industry, but the reasons are far more complex than merely being uncomfortable with change. The well established and well respected field of diffusion research helps to provide explanations as to why new ideas and products often take a long time to come into widespread use, or indeed fail to diffuse at all. Getting a new idea or product adopted is never easy, as Rogers [4] has pointed out: this is especially true of building where new products and product improvements, like established products, are all dependent upon decision makers in the industry for their selection, a process known as specification.

The diffusion work is important because environmentally responsible ideals and practices involve the adoption of both new technologies (hardware) and new ideas associated with it (software). Indeed, from the general diffusion model we should not be surprised if the adoption of environmentally responsible ideals and practices is a lengthy business. Diffusion literature has identified a number of factors that are influential in the diffusion of an innovation and although the field has been developing for over fifty years it is only recently that Rogers's model has been applied to the building industry [5]. Central to the diffusion and adoption process is the individual's 'innovation-decision process' during which the individual either ignores or seeks further information about a new idea or product. He or she must be aware of it in order to consider it for adoption.

As both building designers and specifiers of building products, architectural practices could be seen as important agents of change within the built environment. Although a small proportion of architectural practices are leading the way through innovative design and the selection of new materials to achieve a sustainable goal, it has been argued that the majority of practices have been slow to change their behaviour, preferring to stick to well known design solutions and familiar products [6], their palette of favourite products identified in earlier research. [7].

This paper presents the findings of a research programme that sought to investigate how management techniques employed by architectural practices limit, and often conflict, with a desire to design for a greener environment. The paper seeks to address social and structural issues frequently overlooked by the promoters of sustainable design in an attempt to identify the factors which may influence an architectural practice's design approach within a changing environment.

Fragile Networks

The building industry has a poor reputation for communication. A much cited study from the 1960's [8] drew attention to the lack of effective communication and also commented on the gulf between the designers and the producers, a gulf that has widened over the years. Building professionals rarely work together as part of a 'real' team but are brought together as consultants for one off projects, often with conflicting values and goals and also to the detriment of the product. The temporary project network that forms for each project does not encourage a consistent approach to improvement since networks break down when projects are complete, with individuals taking their experience with them to other temporary relationships. As technology has advanced and buildings have become more sophisticated the number of individual players involved in building procurement has increased, all competing for business in a very competitive market and all chasing after, in many cases, the same fee.

The combination of temporary relationships, a multi-faceted industry, and a variety of different technologies has resulted in over complicated procurement systems with associated complex communication routes. When problems have been identified, such as the architect's inability to manage projects, new management disciplines or niches are created to 'solve' the problem, in this case project management firms have claimed a foothold. Unfortunately these new intermediaries add a further strata, or another link to the chain through which information will pass. The large number of links in the product information chain hinders the opportunity for both continuous feedback and continuous evaluation of design and production. The prospect of improved feedback, so often lacking in the building process, will have implications for durability and in turn a serious attempt to look at the total product life cycle.

In recent years the communication field has been claimed by the information technology (IT) advocates who have claimed that communication will be improved by improved technology. An interesting example of this can be found in a paper by Li [9] who calls for radical measures, in the form of re-engineering, to improve the construction process. The paper states that "An important concern in construction re-engineering is to eliminate the delay of information delivery across different managerial and operational levels." and claims that a new intermediary, in the form of the IT manager, is the person to do it. Whilst we would agree with the quotation, the introduction of yet another link, or gatekeeper, to the product information chain is not the way forward. The greater the number of links in the chain, the greater the potential for ineffective transfer of information (regardless of the technology employed) and the greater the potential for gatekeeping of information.

Robust gates

The filtering or management of information is referred to as 'gatekeeping' in mass communication literature [10]. Any person within the information chain will, to varying degrees, control the information that they receive and pass on to the next link in the chain, thus acting as a gatekeeper to the flow of information. The construct of the gatekeeper was introduced to architectural management literature [11] and has since been extended to encompass the product quality chain [12] in which the gatekeeping model is used to explain why communication within the building industry is ineffective. More specifically, the gatekeeping construct is helpful in looking at how information about building products new to the architects office is communicated to the potential specifiers in the office. In a recently completed piece of work [5] the combination of the gatekeeping model and the diffusion of innovations model was demonstrated and supported by observational research. The new model, based on the specifier's innovation-decision process can now be used to assess the adoption of environmentally responsible products. For the purposes of this paper two pieces of research, carried out separately, but linked, are summarised below.

Summary of the gatekeeping research

A small number of interviews with senior partners, their receptionists and trade representatives were carried out, with the objective of trying to identify the gatekeeping mechanisms employed by private architectural practices [13]. The research found that the architectural offices visited were very resistant to information about new building products, concerned about product failure and the legal implications associated with selecting new products.

Trade literature was assessed subjectively and very quickly by the senior partner who threw approximately 80% away every day. The 20% or so of information allowed through this gate was filtered again in all but the very small practices by a less senior member of staff before it was allowed into the office library where it may have been used by the specifiers in the office. The specifiers who actually selected building products were not involved in the gatekeeping process, but were affected by decisions taken by the gatekeepers because their access to, and awareness of, information was restricted.

The partners also reported that they were unhappy with the quality of the literature provided by the manufacturers and did not like being ‘pestered’ by the trade representatives, who were only invited into the office when they were needed. The trade representatives were aware of the difficulty of getting their ‘foot through the door’ of the architect’s office and had concluded that architects were, for the most part, not interested in new products.

The research found that gatekeeping mechanism were in place, regardless of office size, for two reasons. First, to control information from a risk management viewpoint. The gatekeepers hoped that their experience and their professional judgement would prevent the specification of unsuitable products by other, less senior, members of their office through limiting the information and hence choice of products from which to specify. Second, trade information was filtered to manage information overload by reducing the physical amount of literature entering the office - this was a secondary concern but was linked to risk management. The research highlighted the need for some observational research to record what happened to the literature as it came into an office, found its way (or not) to the specifiers in the office and how the specifiers responded to this literature, reported below..

Summary of the diary of adoption

A number of building products, new to an architectural practice, were monitored over a three year period in an attempt to see when, why and how they were specified through participant observation from within the office. The research was important in recording the senior partner’s gatekeeping actions, the action of the technical partner who acted as a further gatekeeper, the behaviour of the staff who were selecting products from filtered information and the contribution to the specification process from members of the temporary project team, external contributors.

The observations supported the views reported in the gatekeeping research above, with regard to the complexity of the gatekeeping mechanisms. It was evident that the specifiers only sought information about new products when their palette of favourite products did not contain information that was suitable, hence leading to an active search for new information. The importance of the palette of favourite products should not be under estimated since it forms a barrier against the consideration of new products. This, combined with the formally established gatekeeping mechanisms provides a strong barrier to the adoption of new products that may have better environmental credentials.

In one of the situations observed, a planning officer put enough pressure on the architect to force a change of material, from timber boarding (from a renewable source) to a manufactured product (non-renewable source), simply because he did not like the appearance of the timber boarding. However, there was no discussion about the environmental implications of such a decision. Furthermore, there was no evidence in any of the observations that the environmental implications of specifying products, changing them prior to the start of a contract or during the contract (specification substitution) had been considered. Instead the pressure of time, observed in both the pre-contract and post-co-ntract programmes was an overriding factor. Although the research was limited in its scope and was based on traditional procurement systems it does provide detailed case studies of the specification process from inside an architect's office, based on observation rather than memory recall.

A view on managing for sustainability

The issues reported in the research above were confirmed in separate observational research [5] As- such it is useful in highlighting the complex issues associated with the adoption of new products, both from architectural offices' use of robust gates and the pressures exerted from members of the temporary project team, the fragile networks.

In both research programmes it was evident that the firm's senior partner, the gatekeeper, was controlling the flow of information to the specifiers in the office, in some instances assisted by a second gatekeeper (a senior member of the office). We should not be surprised by this since senior partners will wish the office to act collectively in his or her image by following certain design approaches, through limiting the use of unfamiliar (thus risky) products and limiting the time spent by staff researching them. Thus it is the partners of the firms who clearly have significant influence over the use of new products and to which the environmentally responsible argument should be directed if an architectural practice's design approach, within a changing environment, is to change.

In the second research programme the importance of external contributors to the process were noted. These ranged from town planning officers requesting changes to external materials, quantity surveyors suggesting cheaper products to reduce the overall (initial) cost of the building contract, and contractors attempting to change products to cheaper alternatives both at the tender stage and whilst construction was ongoing. Perhaps more importantly, the adoption of building products that were new to the office was shown to be a rare event and difficult to observe.

The research summarised above has practical implications for specifiers and for manufacturers of new products given the emphasis on sustainable design and the selection of 'green products'. Since these products will be perceived as innovations by specifiers (and therefore assessed against existing behaviour, represented by the palette of favourite products) the adoption of such products is likely to take longer than the proponents of environmentally responsible design would like to believe. Indeed, it is likely that many of these products will be stopped at the architectural office's formally established gates because of both their unfamiliarity and the perceived risk of using them. Furthermore the research highlighted the pressure put on the specifier to change products that were unfamiliar to them, to ones that were. Again it is reasonable to assume that 'green products', if specified by the architect, may be substituted by more familiar products during the detail design and construction phases, the innovation-decision process.

The use of electronic media, such as CD ROM and the internet may help the manufacturers to overcome (or get through) the gatekeeping mechanisms employed. But firms are reluctant to pay for a service they can get free through the post in the form of paper literature. The Building Research Establishment have pioneered the 'Information Gateway' [14] although there are problems here in policing the information provided on the inter-net for accuracy. If manufacturers could get together to provide reliable, up to date information that clearly identified the product's environmental credentials (rather than marketing hype) via the internet they will have an ever open gate to the specifier. However, it should be noted that such a system is, according to the research reported above, still reliant on specifiers looking outside their palette of favourite products.

Conclusion

This paper has attempted to highlight some of the social and contextual issues associated with the adoption of environmentally responsible ideals and practices, drawing on both diffusion of innovations and gatekeeping literature. The summaries of the research have indicated that the management systems employed by architectural practices in the form of both formal and informal gatekeeping systems does limit the specifiers exposure to information about new building products. The newer the product to the practice, the greater its perceived risk (consistent with diffusion research) and the greater the likelihood of it being rejected at the formally established gates. As such the actual specifier is, for the most part, denied access to information about new products unless awareness comes from a source that has by-passed the formal gates.

The- architect is arguably the only player capable of providing the holistic view required to bring about quality and an ethical approach to sustainable construction, although on the evidence presented above it would appear that inertia to change is restricted through an attempt to manage risk, information overload and the effective use of staff time. Furthermore, the contribution to the specification process from other members of the temporary design team, such as the client, planner and contractor needs to be recognised and researched further, since all of those involved in the selection of building products have a role to play in the quest for environmentally responsible building.

References

1. Samuels, Robert (1997) 'Lifestyle at the Edge of Chaos' in Madi Gray (ed.) Evolving *Environmental Ideals: Changing Ways of Life, Values and Design Practices*, Royal Institute of Technology, Stockholm, pp.7 l-8 1.

2. Newton, T. and G. Harte (1997) "Green Business: Technicist Kitch" in *Journal of Management Studies,* 34: 1, January, pp. 75-98.

3. Eclipse Research Consultants, (1996) *Environmental Initiatives in the UK Construction Industry: 199.5 Survey of current Practices,* Eclipse Research Consultants, Cambridge.

4. Rogers, Everett M. (1995) *Diffusion of Innovations,* (4th edition.) The Free Press, New York.

5. Emmitt, S (1997) *The Diffusion of Innovations in the Building Industry,* PhD Thesis, University of Manchester, Manchester.

6. Emmitt, S (1997) 'The Diffusion of Environmentally Responsible Ideals and Practices' in Madi Gray (ed.) *Evolving Environmental Ideals: Changing Ways of Life, Values and Design Practices,* Royal Institute of Technology, Stockholm, pp.41-49.

7. Mackinder, Margaret (1980) *The Selection and Specification of Building Materials and Components,* Research Paper 17, University of York Institute of Advanced Architectural Studies, York.

8. Higgin, G. & Jessop, N. (1965) *Communications in the Building Industry - The Report of a Pilot Study.* Tavistock Publications, London.

9. Li, H. (1996) "The Role of IT Manager in Construction Process Re-engineering." in Building Research and Information, **24**:.2, pp. 124-127.

10. Shoemaker, Pamela. (199 1) *Gatekeeping* Sage Publications, London.

11. Emmitt, S. (1994) "Keeper of the Gate", in The International Journal of Architectural Management, Practice and Research, .**8**, pp. 23 - 26,

12. Wyatt, D.P. and Emmitt, S. (1996) "The Product quality Chain - Myth or Reality?" in *The International Journal of Architectural Management, Practice and Research,* **11**, pp 14 - 22.

13. Emmitt, S. (1997) *The Keepers of the Gate,* Research Trust Report, Royal Institute of British Architects, London.

14. Parand, F. (1996) "Construction Industry Knowledge Base," in S. Emmitt (ed.) *Detail Design in Architecture,* BRC, Northampton pp. 82-87

Research for Sustainable Development in the Construction Processes

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Abstract

A lot of good technical research is produced, unfortunately the results are not always used properly in the construction processes and resources are wasted. This implies that more attention must be focused on implementation and change.

There is also a need for clear communication and agreement between different interested parties and participants to achieve research that provides a contribution to the sustainable development of society. An increased understanding and respect for different types of research and research processes will also contribute to a sustainable development in the construction processes.

The purpose of this paper is to describe four different research processes depending on the different aims for the research. The model presented, hopefully, can be a frame of reference in discussions between research departments, customers, clients and researchers.

This paper is based on a report produced in co-operation between the Productivity Group at the Danish Building Research Institute, the Department of Construction Management at Lund University and the Department of Civil and Mining Engineering at Lulea University of Technology.

The intent of the design description is to clarify the profile of the research project as a whole. This includes decisions regarding type of research, i.e. whether the project shall be given a descriptive, evaluating, change directed or theory building design. It is also done in order to judge the research question relative to cost, time and available resources as well as its practical application.

All types of research (technical, economic, behavioural.. .) must be used to contribute to sustainable construction. All partners in the research process must understand the limitations for each type of research.
Keywords: Change, design, development, evaluation, process, research, research methods, scientific society.

1 Introduction

Research contributes to changes and development of various functions in society. At the same time, research is influenced by the society such as changes in business activities and political decisions. With research departments as a part of the society, there is a need for clear communication and agreement between different interested parties and participants to develop research which makes contribution to sustainable development. Constant changes in society mean that researchers are continually faced with new demands and challenges. It is important that the research process supports a sustainable society from the perspective of environment, technology, economy and humanity.

Much technical research is produced, but unfortunately the results are not always used properly in the construction processes and resources are wasted. This implies that more attention must be focused on implementation and change.

The purpose of this paper is to describe four different research processes depending on the different aims for the research. The model presented hopefully can be a frame of reference in discussions between research departments, customers, clients and researchers. At best the model should increase the understanding of each others roles and responsibilities in decision making, planning, producing and reporting the results of research and it will be clear what contribution research can make.

This paper is based on a report [1] produced in co-operation between the Productivity Group at the Danish Building Research Institute and the Department of Construction Management at Lund University. Both institutions have a common interest in strengthening the development of the construction process. In the final stage of the work, the author was appointed Professor at the Department of Civil and Mining Engineering at Luleå University of Technology, and then this department also become involved in producing the report. The methodological literature used in the process of making the report is printed in chapter 5 [2-14].

The research at the various institutions is focused on different phases of the construction process; design, planning, production and maintenance. Research questions which are dealt with are found within different areas such as housing costs, cost development, choice of materials, building physics, load bearing structures, questions on quality, structural design and environment.

The departments also look into how research results are adopted to contribute for sustainable development in the construction area and what are the consequences for new knowledge within the building process. Examples of research areas are:

- How to evaluate the developing process of construction business
- How different areas in the production process interrelate

The common starting point for research activities has to be to achieve a better insight into the building process. A holistic understanding is reached by collaboration and teamwork between researchers and the partners of the building process. This also contributes towards research that is easily applicable and useful. An ongoing development of knowledge about the building process is undertaken on the personal initiative of the researchers as well as through communication and co-operation with the industry, other researchers and experts in the areas of specialisation that are affected. In this manner, the building process is in focus from both an economic, technical and social perspective. Research should be given the direction and status it needs in order to gain the respect of the scientific world. At the same time, it should be easy to understand and to apply within the building sector.

2 Research design

To provide relevant results, the research projects has to be properly designed. A comprehensive view regarding the intent, planning, conduct, expected results of the research project as well as aspects of implementation must govern the project work.

The intent of the research design description is to clarify the profile of the research project as a whole. This includes decisions regarding type of research, i.e. whether the project shall be given a descriptive, evaluating, change directed or theory building design. It is also done in order to judge the research question relative to cost, time and available resources as well as its practical application. The research is also influenced by ongoing international research. This means that when creating the research design, the researcher defines activities, target groups for collection of data as well as economic and time frames for the research project. Research design also includes an estimate of the accessibility of data along with a description and reasons for focusing and scooping the content at the research. Pre-studies and reference groups, if any, are described by function and planning/disposition together with the organisation and available resources of the project.

The research design has to be realistic in relation to prevailing economic frameworks, accessibility of information and other prerequisites for the project. The research design created by the researcher is analysed together with customers, clients, researchers and representatives from the management of the department, instructor/supervisor and financial suppliers. It is important that the researcher has an understanding for both the building process and the research process when choosing research method. The choice ought to be done in relation to both the object being built or the production process which will be studied, as well as the type of research which is intended. Qualitative methods are often most suitable, when doing research related to the process of change, as this type of research involves questions which are described using a large number of non-quantitative variables.

3 Four types of research designs

The matrix in table 1 describes the intent and direction of research relative to choice of research question, choice of method, collection of data, analysis and presentation of results. The horizontal axis of the table describes the research process and the vertical axis the type of research. The research design describes the type of research and all steps in the research process.

		Research process				
Type of research		Research question	Choice of method	Collection of data	Analysis	Presentation of results
1	Change/ Influence	What and how to change	Case studies of change in the organisation/ work-site	Observations and questions	Data feedback, expanded collection of data	Work material, Seminars, reports
2	Evaluate/ Describe	Characterise study of material, behaviour and processes	Surveys at different study objects	Quantitative/ qualitative surveys	Description (part, whole) connection/ reason	Pedagogic presentations
3	Theory or model development	Develop new theories/ models	Studies of published results	Collecting results of empirical and theoretical studies	Combine known knowledge into new structures	Models or theories presented in articles
4	Tests/ Examinations	Behaviour of material/ people in controlled situations	Laboratory tests, experiments	Measurements, simulations	Testing of hypothesis	Scientific papers

Table 1. Type of the research and the steps of the research process.

An analysis of the type of research has shown that, it can be divided into at least following four categories (1) change/influence, (2) evaluate/describe, (3) theory or model development and (4) testing/examinating. Table 1 shows principle relations between the type of research and the research process.
There are no strict boards between the four research types. Some projects can be hard to specify into one research type. The results from one project can and should be used in another project with another type of research. For example, results from tests/examinations regarding toxic materials can be used as input in a project directed to change. An evaluating research can be used in order to find the effects of a change process that are supported from researchers work inside an organisation.

The combinations of different research types will together contribute to a sustainable development. The four types of research will be described below.

3 .l Change/Influence directed research

A research process whose main intent is to contribute to changes in a daily activity is closely related to a work situation. Often, it is the activity which constitutes the focus in a change situation. The aim of the change could be to implement material, work-processes and values that supports a sustainable development. Examples of the variables for investigation are the economic situation, seasonal variations, rules for handling capital, market demands, and teamwork between various partners in the building process or production methods.

To investigate this matter, it would be natural to choose some form of case study. Specific variables are studied as well as how these in various ways influence the target of change; pro and con. How the problem is expressed is to effect change. The choice of method has to be done in such a way that people who are affected by the change are engaged in the research work. Methods for collection of data are focused on both structures and processes in the activity. The amount of quantitative data is often very large. “Feed-back” of collected data is important when making the analysis. Its goal is to create insight and understanding of questions regarding change and research.

For work on change to be successful it is necessary that the collection of data contributes to increased understanding of processes of change. Documentation contains information regarding variables which could contribute to changes. A great deal of the critical examination and the scientific contribution is validated directly by those involved in the process of change. Models and theories could be created through analysis and processing of many case studies/ change projects from a scientific point of view.

3.2 Evaluating/Describing research

Research meant to evaluate ought to have a very clear description of what is being evaluated. The aim of the evaluation could be to find out how waste are managed, what criteria to use when choosing building materials and what impact the concept of sustainable development has in the process of tendering.

These target descriptions direct the choice of the research process, i.e. choice of target group, variables for study and methods for analysis of collected data. Documentation of research results has a primary function as different parties avail themselves of the research result from their background and specific needs.

The pedagogic design and structure of research reports determines how different parties avail themselves of the result of the evaluation. Many evaluations are presented in such a way that results do not reach the parties of the research area. A scientific examination of presented results could be made by other national/domestic or international experts and research groups. From a scientific point of view, there is general knowledge to be gained by processing and analysing complementary investigations and research.

3.3 Theoretic or model building research

Research directed towards theory building is intended to advance the frontiers of knowledge within clearly defined areas. It might involve particular questions within for example structural design and strength of materials, but also building models around specific functions of the building process that support sustainable development. Therefore, the research question is focused on specific models or systems to make specific processes or part processes more effective. In turn, these specific areas of knowledge could be integrated into a wider area of knowledge, i.e. CAD/CAM-models and other IT-tools for specific parts of the building process.

Methods used are very specific to subject and are often carried out by experts within very narrow areas of specialisation. Collection of data is done through a systematic search of previously conducted research studies and constant exchange of experiences with international partners. Empirically defined investigations might also complement the collection of data. Collected data is mainly analysed through combining known knowledge into new structures. Experiences and results that have been achieved are primarily intended for researchers within the area of specialisation and would be published mainly in scientific papers in journals of good renown.

3.4 Testing/Examining research

A fourth area of research is testing research. Its primary intent is to investigate and explain the function of specific components or materials, often made in a laboratory environment.. The research question might be strength, types of cracks in concrete or steel etc. The laboratory can also be used to arrange a specific situation where persons or groups are discussing ore making analyses of there values and how these values supports or hinders a sustainable development.

To get answers to the questions, a research process is chosen in which a single variable is isolated and manipulated. Formulation of problems is often expressed as hypotheses which are tested by experiments. The data acquisition is quantitative with a precision sufficient for the purpose. Computer simulations are used first to reproduce the test and secondly to widen the database. Statistical methods are used for the development of design formulae and also for reliability analysis. The international publication is an important part of the scientific contribution.

4 Conclusions regarding choice of research design

Within technical research different institutions and departments have strongly varying types of research. You will find very qualified experimental studies, evaluation of both building processes and building products and action research. Certain departments work very close to companies and various organisations with the intention to contribute to measures that can increase the quality as well as productivity in the building process. Others carry out experimental studies on material and technical questions on function.

In order for different types of technical research to become successful within its respective field there is a need for increased understanding and respect for different types of research and research processes. Often, qualitative aspects turn out to be worth taking into consideration during implementation of results obtained from experimental situations that focus on quantitative aspects. Simulated experiments and statistical analyses often give an active contribution towards insight and understanding for different needs regarding changes.

All types of research must be used to contribute in sustainable construction. All partners in the research process must understand the limitations for each type of research.

5 References

1. Borgbrant, J. and Andersson, N. (1998). *Research* processes *and scientific character.* Lulea University of Technology, Lulea.
2. Yin, R. (1989). C*ase* study *research.* Sage Publications, Inc. London U.K.

3. Andersen, I. (1990). *Valg af* organisations - *sociologiske metoder.* Samfiindslitteratur, Danmark (in danish).
4. Arbnor, I. and Bjerke, B. (1977). *Företagsekonomisk Metodlära,* Studentlitteratur, Lund.
5. Arvidson, P. and Rosengren, K E. (1992). *Sociologisk metodik, fjärde upplagan.* Almqvist & Wiksell (In Swedish).
6. Borgbrant, J, (1987). *Strategisk dialog.* Natur och kultur, Stockholm (In Swedish).
7. Borgbrant, J. and Hansson, F. (1995). *3T-arbetet vid Skanska Syd AB - en utvärdering.* Institutionen for Byggnadsekonomi, Lunds Universitet, Lund (In Swedish).
8. Holme, I M. and Solvang, B K. (1991). *Forskningsmetodik, om kvalitativa och kvantitativa forskningsmetoder.* Studentlitteratur, Lund (In Swedish).
9. Kristoffersson, A. (1995). *Leaning för effektivare byggproduktion -former för samverkan på byggarbetsplatser.* Institutionen for Byggnadsekonomi, Lunds Universitet, Lund (In Swedish).
10. Maccoby, M. (1988). *Arbeta - varför det?* Svenska Dagbladets Förlag, Borås (In Swedish).
11. Molander, B. (1993). *Vetenskapsfilosofi, en bok om vetenskap och den vetenskapande människan.* Thales, Stockholm (In Swedish).
12. Repstad, P. (1993). *Närhet och distans, kvalitativa metoder i samhällsvetenskap.* Studentlitteratur, Lund (In Swedish).
13. Thuren, T. (1993). *Vetenskapsteori för nybörjare.* Runa förlag, Stockholm (In Swedish).
14. Tognazzini, B. (1992). TOG *on Interface.* Apple Computer Inc, Addison-Wesley, USA.

Environmental Cost, a decision support model

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Abstract
The budget plays a major role during building design and construction. How to keep a project within budget is a source of endless discussion. The Dutch Government Building Agency also maintains a so-called 'environmental budget' to take account of the environmental aspects of each project. This enables us to monitor the 'environmental costs', in a similar way to the financial budget, to ensure that they too stay within their allotted budget. By 'environmental costs' we mean what it would cost to prevent or repair the environmental impact of the construction and use of a building.
An environmental budget is drawn up based on the Schedule of Requirements and the client's environmental ambitions. This indicates what environmental costs the project may involve. An estimate is then made of how high the environmental costs of construction and use of the building would be if the proposed design were carried through. The methodology runs parallel to that of commercial cost control systems. At the start of the project, the environmental cost estimates are only approximate; as the project proceeds, these figures become firmer. On completion, an overall costing is done. The technical data that result from this are used as a basis for initial estimates when preparing the next project.
A practical example of an environmental cost calculation is included.
Keywords: environmental costs, environmental budget, environmental economy, cost control.

1 Introduction

There is a growing interest in the Netherlands in sustainable building, and the concept has attracted considerable government attention. A few years ago Parliament adopted a plan of approach for sustainable building, the results of which were recently evaluated. They indicate that the concept is beginning to have an impact in residential construction. A second plan was approved at the end of last year which included a significant emphasis on commercial and industrial construction, and sustainable town planning. Many local authorities are now also actively pursuing sustainable building policies. Discussions in the construction industry have led to agreement on a package of environmentally friendly measures that have practical application in residential construction. A similar set of measures for commercial and industrial construction is now in preparation. Utrecht, a city in the heart of the Netherlands, has had an information centre for sustainable building for some time. The centre is a focus for a lively exchange of knowledge and ideas between commercial concerns, universities, and national and local authorities.
The Dutch Government Building Agency has played a pioneering role in these developments. As one of the biggest commercial and industrial construction clients in the country, the Agency has been able to encourage the implementation of a national sustainable building policy. When we started doing this in around 1990, lists of all kinds were circulating in the Netherlands giving details of environmentally friendly materials and others deemed much less desirable. Timber, for example, was presented as a building material which had less impact on the environment than aluminium. This, however, ignored the way in which timber and aluminium are used in construction. Timber structures are usually relatively heavy, whereas thin sheet aluminium can be

applied as a facade cladding. This leads us to ask what is better for the environment: large quantities of timber or much smaller quantities of aluminium? This whole question prompted us to start looking for a quantitative evaluation system. We eventually came up with the TWIN model. Further details of the model can be found in the paper given at the CIB World Building Congress 1998 [1] by Michiel Haas, the model's spiritual father.

2 An integrated standard for sustainable building

The introduction of the TWIN model alone is not enough, however. There is more to sustainable building than simply the environmental qualities of building materials. We also have to consider energy and water consumption, and the environmental impact that is linked to choice of location. It makes a considerable difference, for example, whether an office building is placed near a motorway and given generous car-parking facilities, or right next to a railway station with hardly any parking spaces at all. In the latter case, the office staff will make more use of public transport, with consequent beneficial environmental effects from reduced private home/work traffic. If we want to evaluate the environmental aspects of a construction plan, therefore, we need to examine a number of factors, such as:

- choice of building materials
- energy and water consumption
- environmental impact of home/work traffic

In practice, these factors are interconnected - for example, if we wish to compare an energy-efficient new building situated next to a railway station with the renovation of an existing building located some distance from the station. The energy-use and mobility factors associated with a renovated building often have a greater environmental impact than those associated with a new building, whereas the materials input, by contrast, is substantially lower. The question then is: which solution causes the least environmental impact — new construction or renovation? In answering this question, it is useful to have some way of adding up all the various individual factors to enable us to compare the total environmental impact of each alternative.

We decided, therefore, to express all environmental effects in financial terms. We do this by first ascertaining the scale of the environmental effects and then calculating how much it would cost to prevent or repair those effects. We published guidelines for this method of evaluation in a so-called 'Easter letter' in 1996 [2]. Following this, a foundation was set up[1] which developed the concept into a fully-fledged professional programme, that is now on the market in the Netherlands under the name 'GreenCalc'.

3 GreenCalc, a calculation in three steps

1. The calculation starts with a quantification of the environmental effects. This involves ascertaining the environmental impact of a building's construction and use.
2. This environmental impact is then accorded a monetary value. To do this, we calculate what it would cost to prevent or repair the environmental impact concerned. These prevention-or-repair costs are referred to as the 'environmental costs'.
3. The calculations we subsequently carry out based on the environmental costs give us a total figure for the environmental impact of a building and its use.

In summary, the calculation model looks like this:

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Q → **$** → **Σ**
quantification → monetary valuation → balance calculation

It would be beyond the scope of this paper to elaborate on these three steps in great detail. We shall instead limit ourselves in the following sections to a few general guidelines, and then expand on the way in which we use the model in practice.

3.1 Quantification

The calculation method starts with a quantification of the environmental effects. Life-cycle analysis (LCA) is the most widely known method for doing this. This analysis surveys the environmental impact of, for example, a building material over the whole life-cycle of that material: from the extraction of the raw materials through to the processing of the demolition debris. In so far as the data needed are available, the method gives a reliable picture of the environmental impact. The fact that this LCA picture cannot be complete because the required data on some environmental effects are not known led Michiel Haas to develop his TWIN model [1]. Using a specially developed system to produce qualitative estimates, he is able to fill in the gaps left by the life-cycle analysis.
Besides the TWIN model we also use other, less recently developed quantification methods for (anticipated) energy and water consumption. An estimate is also made of the fuel used by related home/work traffic. The picture we arrive at shows us the extent of the environmental impact of:

- building materials
- energy and water consumption
- mobility (home/work traffic)

3.2 Monetary valuation

The second step in the GreenCalc method is the conversion of the environmental effects into monetary values. We do this in collaboration with the Erasmus University in Rotterdam. The university's Faculty of Environmental Economics is a centre of expertise in the monetary valuation of environmental impact. Together with the Faculty, we determine what it would cost to prevent or repair the environmental impact of a building.
The following is an example of this approach: the energy used in the production of building materials contributes to acidification of the atmosphere, and this pollution in turn damages buildings and natural areas. The costs of repairing this damage are not included in the price of the building materials. These costs are quietly passed on to others. In maintaining historic buildings we encounter damage to facades and ornaments caused by acid rain. The repair costs have to be paid by the proprietor of the building, while those responsible for the damage are well out of range. Within the Government Building Agency these, 'hidden' environmental costs are brought to the attention of the decision-makers. They are not yet being asked to pay these costs, but in the longer run that is perhaps the way we have to go. The decision-makers are currently only being asked *to justify* these environmental costs, but they need to investigate the possibility of other solutions to lower them.

3.3 Balance calculation

The GreenCalc method is highly analogous to the traditional calculations made in the real estate sector. The use of building materials, for example, is seen as an investment in environmental goods. As in the commercial economy, this investment is gradually depreciated over time. One striking difference, however, is that commercial calculations depreciate an investment over its *economic or functional life-time,* whereas environmental investment *takes the technical life-time* as the basis for depreciation. This was a conscious choice, because we believe that sustainable building is not just about the design and construction phases, but includes a building's period of use too. In this utilisation phase it is advantageous to maintain a building's functionality as long as possible. There is a certain wastage when a building is demolished before the end of its technical life; the technical usage value of the invested environmental goods is not fully realised. This necessitates the premature use of additional environmental goods for new construction, and is another cost item on the environmental bill, This effect can be brought into the overall picture by depreciating environmental investments over their technical life-time.

Future environmental costs are also calculated in the same way as they would be commercially. From these costs we calculate a monetary value over the anticipated period of a building's use, and this figure is taken into account when evaluating an investment. It is then a matter of looking at the environmental costs of expected energy and water consumption and mobility.

4 A common language

Many of the decisions taken in the construction industry are based on commercial considerations. The decision makers think about lines of money. We want to follow this line of thought by making our calculations, using currency. Environment and economics are then speaking the same language, and this simplifies the decision-making process.

Environment & Economics

5

a common language

As with economic judgements, environmental aspects are not assessed purely on the basis of the costs, but also in terms of the cost/quality ratio. The environmental costs provide a 'price tag'; they do not say anything about quality. As with the other aspects of a building, the axiom that the cheapest solution is not always the best solution also holds for the environmental aspects. The environmental costs do not, for example, tell us anything about the functionality of a building, nor the way it is experienced by those using it. It is therefore important that the environmental costs are always weighed up in combination with the quality of the design in question. For a discussion of the quality assessment of a building plan, we refer to the paper by George Ang [3]. The performance concept - which he discusses - and the environmental costs - which are discussed here - are, as it were, two sides of the same coin.

5 Consecutive calculations over the whole life of real estate

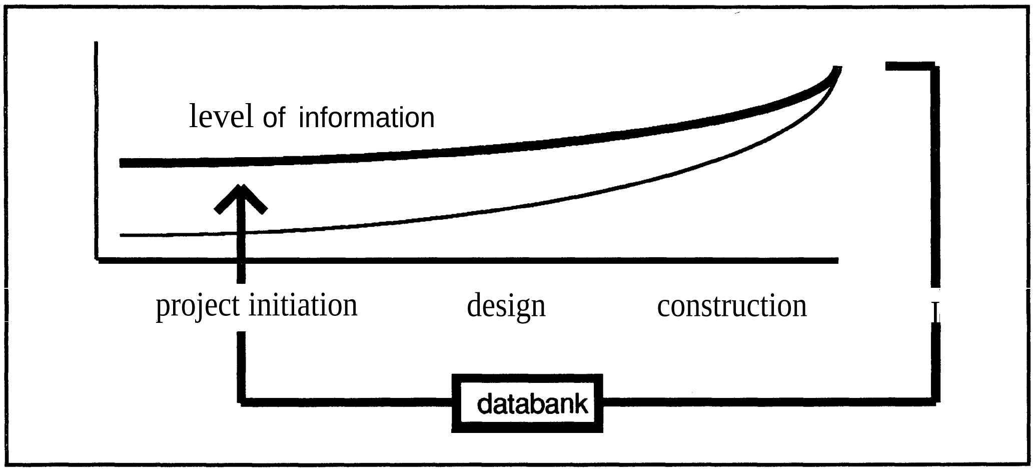
The construction process entails a whole chain of decisions. From the very first initiative right through to completion, choices continually have to be made — as George Ang demonstrates in his presentation to the CIB World Building Congress 1998 [3]. The task each time is to match supply to demand. What does the client want and what is feasible in practice?

In order to gain a clear picture of the environmental aspects of supply and demand, the Government Building Agency calculates the environmental costs several times during the course of a project. This begins with the initiation phase, and continues through design and construction and on into the utilisation phase. GreenCalc has sets of calculation results relating to each phase of a project. This can be summed up as follows:

Project phases	GreenCalc calculation results
initiation phase:	establishment of environmental budget
design and construction phase:	environmental costs versus budget
utilisation phase:	environmental profit and loss account

5.1 Initiation phase

An environmental budget is drawn up based on the Schedule of Requirements and the client's environmental ambitions. This indicates what environmental costs the project may involve. In this initial phase, when relatively few details of the project are yet available, estimates have to be made. Here too the methodology runs parallel to the commercial approach. At the start of the project, the cost estimates are only approximate; as the project proceeds, these figures become firmer. On completion, an overall costing is done, The technical data that result from this are kept in a databank and used as a basis for initial estimates when preparing the next project. This technique makes a more sophisticated level of information available at the beginning of a project, something which is very important given that it is during this early phase that the most radical decisions have to be made - think, for example, of the consequences of the choice of location and the choice between renovation and new construction.



5 ● 2 Design and construction phase

A 'do-it-yourself' version of GreenCalc is available which enables a project team to make its own estimates of environmental costs, At a suitable stage — but in any case before the tender — official calculations are made, and the input data verified as correct. The results are presented to management in the form of a so-called 'Environment Chart', an example of which is attached. On completion, the final results are set out on another Environment Chart. If these results meet certain specified requirements, a certificate can be issued.

5 . 3 Utilisation phase

Commercially, in the real estate utilisation phase a profit and loss account is kept in which the annual operating costs are set against annual income. Costs include depreciation, interest charges, maintenance, management, and so forth, and are set against benefits such as rental income. In environmental accounting we also have costs, but the income side is less clear. Here the profits consist of the social functions that the buildings perform which are valued by the community. Consider, for example, the social function of courts and prisons. We can deduce from the environmental budget which the government maintains for these buildings how much they are worth to the community.The use of environmental profit and loss accounts is still in the development stage. The first such account will be drawn up in 1998 for an office building.

6 A practical example

The results of a calculation of environmental costs are presented on an 'Environment Chart*. An example of one of these is included as an appendix. It refers to the renovation of an Amsterdam convent and attached school. These now form a complex which houses an employment office and a temporary employment agency.

GreenCalc modules	environmental budget	environmental costs	result
floor area (gfa = gross floor area)	1.715 m² gfa	2.448 m² gfa	
environmental book value of existing		NLG 750.000	
building		NLG 1 .000.000	
building materials for renovation	NLG 3.900.000	NLG 1.750.000	45%
total building materials	NLG 2.700.000	NLG 4.500.000	170%
energy consumption*	NLG 20.000	NLG 20.000	100%
water consumption*	NLG 900.000	NLG 700.000	80%
mobility (home/work travel)*	NLG 7.520.000	NLG 6.970.000	90% of **the budget**
TOTAL			
* cash value over the period of use			

This table has been formulated using a calculation model which is still under development; the figures are indicative.

In the above table — taken from the Environment Chart - the environmental costs are compared to the environmental budget. The budget is based on a new building, efficiently designed according to Government Building Agency guidelines. The table shows that the environmental cost of building materials is only 45% of the budget. The figure is so low because the building is *60* years old. Hence the environmental investment has been written off to a large extent. The project architect, Wim van Rijn, also managed to adapt the building to its new function with minimal alteration.
Against the plus of the very low materials requirement, we have the definite minus of high energy consumption. The building is very generously proportioned and the employment office takes up far more space in this building than it would in a new building *(2,500* m2 as opposed to 1,700 m2). The energy required to heat and light this extra space pushes consumption way up, and works out at 170% of the norm for new construction. This cancels out the advantage of low materials input.Taken altogether, the environmental costs are 90% of the norm for new buildings. On these grounds it might be assumed that it makes no real difference to the environment whether we renovate or put up new buildings. On the contrary! The building concerned had been empty for years. A great sombre colossus, covered in graffiti, that dominated the whole square in which it stands. It takes up one whole side of the square and affects the atmosphere of the surrounding area. The renovation has not just revived the building, but has brought the whole square back to life again. The shops and houses around the square have increased in value, with houses being improved one after the other. By renovating the convent we have also indirectly extended the useful life of dozens of adjoining buildings. The environmental gain of this effect on the surroundings is not yet factored into the calculation of environmental costs. We are working hard to expand GreenCalc to include a module on 'space utilisation', which attempts to assess a building's effects on its immediate environment. We are not there yet, but it is clearly evident that this type of renovation actually has no environmental *costs.* If we add in the effects on its surroundings, we are undoubtedly looking at a substantial environmental *profit..*

References

1 Haas, M. *(1998) The TWIN model, an environmental calculation method as performance concept,* CIB World Building Congress 1998, Gävle, Sweden

2 Dewever, L.M. (1996) *Easter letter,* Government Building Agency, PO Box 210, 6800 AE Arnhem, The Netherlands

3 Ang, *G.K.I. (1998) Sustainable design/construction and the performance concept,* CIB World Building Congress 1998, Gävle, Sweden

Appendix

Environmental chart of the Amsterdam-Zuid Employment Office.

Basic approach methodologies for buildings' management in mountain environment. Case study.

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Abstract
Sustainable development is more and more the keyword according which every efforts must be made to assure the maintenance and a suitable transformation of the mountain territory and of the cultural and historical heritage represented by its settlements, to allow the development and the fulfilment of requirements of the modern life.
The belonging to sites with specific geographical and morphological features, which have deeply influenced the existence and the availability of natural resources for long time, affects as a determining factor the built objects and the technical infrastructures, for what concerns as the choices related to the building materials as the building systems employed into their construction.
The paper deals with the case study of the residential buildings of the mountain communities of the eastern Alps in North Italy, with particular reference to some peculiar building typologies of the vernacular architecture.
The study aims to set out the basis to fix operative tools for the maintenance management of such built estate, and to point out some sustainable design choices as for the reuse and the rehabilitation of old buildings as for the new buildings, this aim could be pursued throughout a reappraisal, even from an economical standpoint, of these areas which potentially offer the opportunity of a wider exploitation to shrewdly managed for the safeguarding of the cultural values to be transferred to future generations.
The analysis of the area showed some recurring situations, summarised as following : the progressive abandonment of large areas, the development of new settlements for residential/productive purposes close to ancient historic towns, the building up of totally new urban centres. A basic methodological approach to the management of the building stock is given as answer by the study, according to the following criteria : the development of the knowledge and the transmission of the cultural heritage belonging to the mountain environment, with particular reference to the building stock ; a "guided" transformation of the most meaningful sites and built areas still important for the territory ; the reappraisal of the use of local resources and traditional building technics, as in the rehabilitation of existing buildings as in the new constructions.

Keywords : maintenance management, reuse, sustainable materials, wooden buildings

1 Introduction

Mountain territories are rich of scenic and environmental values ; since they were for such a long time uncontaminated places, or affected by slight changes, due to the human settlement and the related activities, today they are much more sensible to whatever intervention. Sustainable development is more and more the keyword according which every efforts must be made to assure the maintenance and a suitable transformation of the mountain territory and of the cultural and historical heritage represented by its settlements, to allow the development and the fulfilment of requirements of the modern life.

Geographical and morphological features of alpine territories have deeply influenced every intervention carried out by men to develop any activity to maintain acceptable living condition and to establish permanent settlements. Mountain economies have been generally characterised, during the past, by poor activities (farming based on the growing of limited vegetal species, aimed to fulfil the requirements of small communities, stock /sheep - rearing characterised by the seasonal moving to different heights, limited productive activities mainly related to the milk transformation process).

Even the social organisation has bees for long time influenced by the territory's severity : the much more diffused model for the settlement in these areas was that of small autonomous communities, gathered in small / medium size blocks of houses (*masi* or farms), spread out on the territory. This typical settlement remained practically unchanged for many generations, even thanks to the existence of strong social-legal institutions such as, i.e., the *maso* ***chiuso*** diffused in the South-Tyrol area since from the middle of the XVIII century.

The diffused architecture of these regions was also characterised by the use of local resources and from archaic forms, by the use of traditional and simple building technics handed down from father to son by carpenters and builders who deeply respected the environment by employing only what the place allowed to use as building materials ; up today this architecture has suffered deep transformations even due to the coming of the so called modernity, able to exceed the natural barriers, which also allows the building of every kind of construction, with whatever material and advanced technologies, even if with high economical and environmental costs.

In this frame we face today the problem to reconcile the respect and the maintenance of typical features of the mountain environment with the need of its sustainable development ; this aim could be pursued throughout a reappraisal, even from an economical standpoint, of these areas which potentially offer the opportunity of a wider exploitation to shrewdly managed for the safeguarding of the cultural values to be transferred to future generations.

2. The knowledge and the analysis of the building stock

At the Laboratory of Building Design of the Department of Civil and Environmental Engineering (University of Trento, Italy), researches are carried out dealing with different aspects related to the building stock in the mountain environment. A first research line is about the study of the traditional building heritage, strongly characterised by the stone vernacular architecture, recurring in the lower valleys, and by the wooden architecture diffused in the medium/high level areas (1). A second research line deals with the more recent building estate, as an answer to the modern living requirements which developed new formal and building typologies not always respectful of the surrounding environment : they didn't either become integrated it or respected traditional use of local materials, giving rise to problems related to their maintenance especially for what concerns the performances of materials and technics not suitable in a so strict environment (2).

The aim of the researches is to point out interventions' methodologies and tools for the management and sustainable transformation of this building stock, with the safeguarding and the maintenance of its cultural heritage ; moreover, the aim is to point out building systems and technics compatible with the delicate balance of the mountain environment, and which can also reclaim the building experience from the past as for materials and technics. Nevertheless, this doesn't exclude the possibility of a new understanding and a supplementing of the last with even strongly innovative materials, on condition that they have a high level of adaptability to the mountain environment and recycling possibilities when different users' requirements ask for a change in the use destination.

The studies carried out at the Laboratory in Trento are part of a wider discussion at the international level on the reappraisal of the technical and building solutions of the traditional vernacular architecture, seen as a man's product able to reach a good balance between the exploitation of the environment and the vital needs of nourishment in acceptable comfort conditions (3).

To fix basic approach methodologies for the management of the building stock in mountain environment, to be followed as guide lines as in the rehabilitation and renovation process of the existing buildings as in the choice of formal, functional and building typologies for new interventions, a starting point has been the analysis of the present situation on a share of sample - territory Some valleys belonging to the territory of the Trento and Bolzano provinces have been examined, in the north-east part of the Italian Alps and pointed out as representative of the changes which interested the mountain habitat following the coming of the modernity with all the related needs and requirements. Meaningful examples of the last are the two opposite conditions of the abandonment and the depopulation of underdeveloped areas and, on the other hand, the extreme exploitation and the transfiguration of the areas with strong touristic bend.

The collection and the arrangement of data concerning the built estate has been carried out by means of recording charts used as analysis tools appropriately studied to enhance and to evaluate some features which strongly characterise the place and its prevailing architecture, and to stress the influence that the first had on the second. These features are : the configuration of the buildings' surrounding ground and environment ; the sides exposure in the valley ; the land arrangement ; the human scale of the settlements ; the access routes ; the recurring formal and building typologies ; the search for their original matrix ; the materials and the technics employed in the production of the building components which are seen as strong marks of the settlements. Moreover, transformations at functional, formal and building level have been examined ; the analysis focused the strong tendency to the change of the original use destination which deeply affected the original building type.

The analysis showed some recurring situations which is important to focus when drawing up intervention proposals for the safeguard and a right management of the territory and its building stock. A first case is represented by the progressive abandonment of large areas with prevailing agricultural bent, with the following advanced decadence of the living centres and oblivion of the cultural value represented by the traditional architecture. The main need is in this case the complete conservation of the sites and their building blocks as authentic witness of the past.

A second case, much more diffused, is represented by the development of new settlements for residential/productive purposes, close to ancient historic towns and the following alteration of the last to the modern requirements for what concerns living standards and fitting with new services and infrastructures. From the analysis of these situations some warning signals must be kept in mind as meaningful of the current way to operate the transformation of the buildings, without respect of their inner cultural values : very often the lacking in the knowledge of the values of the built estate, in the knowledge of the traditional technics and the use of local resources, on which now the modern materials take priority because of less expensive, easy to build up and more "secure" for performances and given comfort, all these reasons lead to the transformation of the traditional features of the vernacular architecture and to the settling side of modern buildings deeply conflicting with the surrounding environment.

The last even less recurring situation is the building up of totally new urban centres or specialised buildings in areas with strong specific bent, as productive as touristic. Problems in this case are related to the need of integration of the new object with the surrounding territory which can be seen as a non renewable resources with peculiar cultural and environmental features to preserve.

3 Methodological proposal for interventions

In a preliminary phase some methodological proposals for further interventions have been promoted for the rehabilitation and the renovation of vernacular architecture, for the cultural values handed down by it, and of its capabilities to become integrated with the surroundings thanks to the sustainable use of the territory and its resources. Criteria for interventions have been therefore pointed out aimed to :

- the development of the knowledge and the transmission of the cultural heritage belonging to the mountain environment, with particular reference to the building stock ;
- a "guided" transformation of the most meaningful sites and built areas still important for the territory ;
- the reappraisal of the use of local resources and traditional building technics, as in the rehabilitation of existing buildings as in the new constructions.

For the areas with an high level of decadence and strong tendency to the abandonment, to maintain built object in situ until it is possible could be a sustainable choice, within a "museum" structure ; to maintain the building heritage could imply the conservation of functional, building and formal typologies, without modifying or changing the original use destination. Basing on the experience in the analysed territories, this can be achieved as for small built areas as for larger areas, through the arrangement of open air museums or eco-museums seen as the pointing out of main ways with landscape and cultural values crossing the built areas, isolated or gathered into groups, with particular cultural interest and meaningful of the vernacular heritage of the region. If this is not possible, but on the other hand it is favourable to keep only few examples, more representative of the past, the possibility can be evaluated to move these buildings in other places than the original, were some totally new "open air museums" can be established, thus recover land in the original areas for new destination.

These proposals can be accepted if supported by strict conditions, such as the accessibility of sites and the available financial and technical resources to maintain, to run and make these places interesting for tourism, thus transforming them into a fruitful activity able to revalue from the economical standpoint the area by bringing new resources to the local community.

A different proposal must be made in case of the renewal the rehabilitation of a building stock with high potentiality for exploitation even if it requires the adaptation to modern standard and the integration with new buildings. This is the case related to the mountain areas which moved from the agriculture and farming bent to the tourism and the tertiary activities, asking more and more for a renovation and enlarging of the building stock.

Looking to similar project developed in rural areas of side regions (4), with similar problems for what concerns the maintenance and respect of landscape and environmental values, some proposals have been pointed out for the control and the management of transformations, such as "guide lines" to be used as executive tools These are intended not as strict rules or "how to do" models to be used in every situation as acceptable building solutions, but rather as "like to do" suggestion among which the user or the owner of the building can choose and adapt to his building that which suits more his needs according to present situation or can be easily adaptable to future changes, limiting the economic and environmental costs.

In this framework the reappraisal of the use of traditional materials and technics take importance, which could allow, as in the past, the suitable exploitation of the prevailing local resources and at the same time an incentive to the recycling as much as possible of materials belonging to old buildings which would be dismantled or deeply renewed. Nevertheless, during the past it was a diffused way to act to recycle and reuse of wooden components from old buildings, such as roof truss, floors, shingles, ecc. These elements, with few and inexpensive maquillages were given as new and with behaviour performances fitting the always new requirements. Moreover, the use of traditional and local materials could also contribute to reclaim and exploitation of the natural environment as also it has been in the past : it allows a low energetic cost, a low environmental cost thanks to low level of dangerous emissions during the production of the building components, low or no transportation costs, low waste during the production process, environmental costs distributed on a long life cycle, high recycling percent of materials and components, even weakened (even the burnt wood could in most of the cases be reused, thanks to the oversize dimensions employed). The use of wood as building materials has always satisfied some conditions which can nowadays be considered basic for the sustainability of a building. Thanks to traditional and new executive modalities, as dry assembling technic for reduced section components the are easy to mount, to replace, to dismantle, to get in the original form and dimension after each use, to be employed in different building sub-system and to recycle after the last use.

The reappraisal of traditional material and technics can also contribute to the safeguarding of the natural landscape : this is the case of the historical forest, which supply material with scheduled growing and cutting, and which development has been guided from long time by the consciousness and the skill of carpenters and builders.

4 Conclusion

Some of the above mentioned proposal, and especially those related to the reclamation of traditional buildings in existing settlements, have been tested in case studies (5) and other are still working out, in connection with some scheduled co-operation programs with local authorities responsible for maintenance and preservation of traditional cultural heritage. From the experiences carried out some remarks can be stressed, the main of which can be summarised as following.

Three are the problems related to a successful application of these intervention proposals : the firs is the lack of a clear legislation for the preservation and the maintenance of this kind of heritage, and at the same time a close plot of authorities dealing with it which can hardly manage the transforming process of the built stock. Moreover, there is often a great difficulty to place again existing buildings with peculiar constructive features within the developing plans for urban areas.

Then, a lack of knowledge of traditional methods and techniques, as modern ones have usurped the role of local builders and carpenters able to produce sustainable buildings.

At last the even high costs for the employment and the revaluation of traditional way of building, if compared to the benefits they can produce.

To all these questions it would be an attempt to give an answer by getting the result of some pilot project which are under development in the area interested by the previous analysis.

5 Acknowledgements

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6 References

1. Frattari A., Garofolo I. (1994) Conservation and modernisation of vernacular wooden architecture of alpine regions. *CIB W79 Tokyo Symposium on Strategies & Technologies for Maintenance & Modernisation of Buildings Proceedings,* pp. 757-764.

2. Frattari A., Garofolo I. **(1995)** Thermal performances of wooden traditional buildings in eastern alpine regions : case study. *Building Physics Symposium - Bauphysik Symposium Proceedings*, Budapest 4-6 Oct, pp. 49-53.
3. Kimura, K. (1997) Vernacular technologies applied to modern architecture for sustainable environment. *2nd International Conference Buildings and the Environment Proceedings*, Paris, pp.677-684.
4. (1996) Vade-mecum des construction rurales du Jura neuchatelois : observations sur le terrain et recommandations. *Rapport final.*
5. Garofolo, I., Rizzi, P. **(1995)** Tecniche costruttive tradizionali nel recupero dell'architettura del legno : un caso di studio. *International Symposium proceedings Il progetto nello spazio della memoria. Segni, idee, potenzialità*, Napoli 27-28 October, pp. 962-973.

A 3D CAD model of embodied energy for assessment of sustainable construction

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Abstract
The concept of sustainable development of human activities has highlighted the environmental impacts of buildings, particularly the use of energy for construction and operation and the resulting contributions to carbon dioxide (CO_2) in the atmosphere from the burning of fossil fuels for energy generation. A system to estimate energy used in creating buildings, and the resultant CO_2 emissions, direct from 3D CAD drawings has been developed to calculate embodied energy, CO_2 emissions and mass for all materials in a building, and to provide graphing and tabulation functions which call upon CAD information to provide a wide variety of breakdowns of energy and CO_2 by element category, material category, and individual materials. The significance of initial embodied energy so estimated is compared with the operational energy over the whole life of a building calculated using other standard models based on heating and cooling loads. This paper discusses this example of integration of evaluation methods from CAD information as well as the operation, uses, limitations, benefits and future role for this type of analysis in designing and managing for sustainability of construction.
Keywords: Embodied energy, life cycle energy, sustainable construction, 3D CAD

1 Introduction

The concept of sustainable development of human activities has highlighted the environmental impacts of buildings, particularly the use of energy for construction and operation and the resulting contributions to carbon dioxide (CO_2) in the atmosphere from the use of fossil fuels for energy generation. A system to evaluate energy used in creating buildings, known as embodied energy, and the resultant CO_2 emissions is needed to complement the models for estimating operating energy of buildings.

To estimate the amount of energy embodied in a building; and the resultant greenhouse gas emissions generated through energy consumed in these processes, prototype software was developed for the CAD package APDesign to calculate the material quantities, embodied energy and greenhouse gas emissions directly from a 3D CAD model [1]. This model provides quantitative values to assist in determining the environmental impact of alternative designs and building materials at the design stage of a building. The ultimate aim of the software is to integrate it with an existing operating energy model to create a procedure which design professionals would use to assess alternative designs in terms of the amount of energy required to construct and operate a building and the resultant CO_2 emissions from that energy generation.

This paper discusses this example of integration of evaluation methods from CAD information as well as the operation, uses, limitations, benefits and future role for this type of analysis in designing and managing for sustainability of construction.

2 Embodied energy

Embodied energy is defined as the quantity of energy required by all of the activities associated with a production process, including the relative proportions consumed in all activities upstream to the acquisition of natural resources and the share of energy used in making equipment and in supporting functions. Buildings have a significant impact on the environment due to the energy embodied in construction materials.

To be able to quantify the energy embodied in the construction of a building, the quantities of materials must first be estimated through a process of disaggregation to a level of detail which allows for the separation of components into their principal materials. Energy intensities of each material can then be multiplied by the quantities of individual materials and the products aggregated to obtain the total for each material, element or whole building.

Embodied energy intensities were derived from input-output tables and other national and international studies. To obtain an accurate and reliable database of embodied energy and CO_2 intensities for all materials used in buildings is an enormous task in itself and is a necessity for detailed comparisons of materials. The main requirement of embodied energy calculations at the design stage is obtaining accurate and useable material quantities and then combining them with currently available embodied energy and CO_2 values.

Previous investigations have calculated the total embodied energy from individual houses (e.g. [2],[3],[4]) and Pullen [5] has formalised the process in a spreadsheet which links to a series of databases for embodied energy calculations for houses. The energy used in the construction process is not of a magnitude sufficient to effect the alternative choices but should be included in the total [6].

3 3D CAD model

The chosen approach to fast and practical estimates of embodied energy, CO_2 emissions and mass values directly from 3D CAD drawings at the design stage requires both 3D CAD and accurate quantity functions to calculate embodied energy values from a database of embodied energy intensities. To avoid duplicating the techniques for estimating quantities from first principles, an existing computer program which provided many of the required functions was selected and then extended. The chosen software was a program called APDesign, a CAD package developed and used extensively in Australia, Europe, Canada and the USA.

APDesign is an AutoCAD based system, tailored to creating 3D models of building designs using a large inventory of standard and custom building items. All building items are entered into the drawing from an object database. Unlike the AutoCAD basis of the system, each line, or group of lines, on the drawing is a known building item, i.e. an identifiable object, with attached functions and associated attributes which relate to the drawing object. A typical detailed drawing is shown in Figure 1.

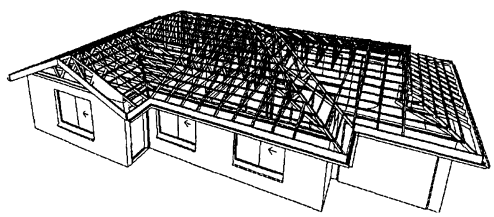

Figure 1 Example of 3D CAD drawing

It was necessary to extend the capabilities of APDesign to further levels of detail beyond the bills of quantities approach which was successfully implemented in the original software. Every item needed to be further disaggregated into its component materials and a generic approach developed to achieve such extra detail with minimal effort. The resulting software makes it a very simple and straightforward procedure for users to access and utilise the embodied energy analysis techniques.

The **embodied energy module** is a specialist tool created to allow embodied energy values, CO_2 emission values and building mass to be calculated automatically from the 3D CAD drawing. The embodied energy, CO_2 and mass intensity values are stored in a material database which is linked back to the building item database of APDesign while the relationships (known as formula sets) are separate databases.

The **building item database** as found in APDesign consists of items used by the construction industry as 3D objects. The database comprises only the critical design information (mainly dimensional parameters) needed to create each item (walls, doors, windows, footings, etc).

The **formulas** are a crucial part of the process to calculate embodied energy. They are used to calculate the quantities of specific materials associated with each building item by using dimensional parameters from the detail of the items and the primary graphic, as held in the building item database. Each building item is made up of one or more materials, each of which has a separate embodied energy, CO_2 and mass value. Therefore, it is necessary to split each building item into a group of materials by associating with that building item a group of formulas, known as a formula set, from which the amount of each material can be calculated. The formula sets are generic, i.e. they can be used interchangeably for similar building items, thus reducing the number of formula sets needed.

The **material database** contains the materials and the embodied energy, CO_2 and mass data associated with them. At present, the materials database contains around 500 materials. These are divided into 20 material categories such as steel, aluminium, timber, plaster, and so on.

The prototype software is the first system which has attempted to design a framework for fast and useable estimations of embodied energy, CO_2 emissions and mass values directly from 3D CAD drawings at the design stage and the future possibility of simulating various design options for comparative purposes.

3.1 Results

The detailed calculated values, totals and percentages of the embodied energy, CO_2 and mass are tabulated and sorted in four ways: by *description* - the same fixed order as used for the element and material categories; by *embodied energy* - in descending order of estimated embodied energy values; by *CO_2 emissions* - in descending order of estimated CO_2 emissions values; and by *mass* - in descending order of mass values. The mass values are displayed because they are calculated as an essential step in the conversion from 3D CAD volumes to the units of mass in which embodied energy are normally expressed.

Graphs enable users to quickly see the relativities of different building items and materials with regard to their embodied energy, CO_2 and mass values and also enable comparisons of different construction techniques and materials, e.g. Figure 2 shows the CO_2 emissions due to embodied energy by material category. The values shown are for a hypothetical project.

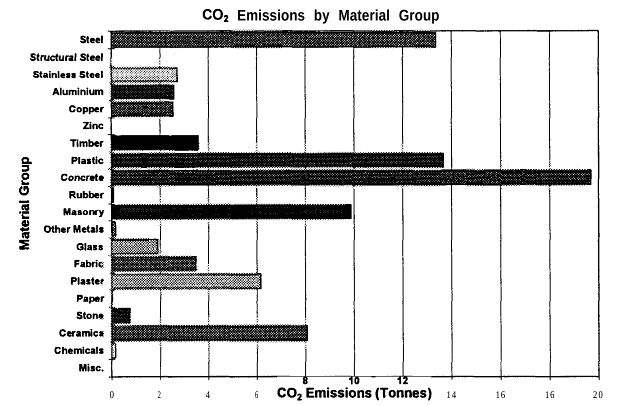

Figure 2 CO_2 emissions by material category

4 Operating energy

While the principles of energy efficient house designs have been known for some time, only a small proportion of new houses are energy efficient in Australia. Typical annual energy usage in Australian houses is shown in Table 1 [Table B.1 NS W/ACT Residential Sector Energy Use. 7, 8]. The annual heating and cooling loads are the most significant contributor and dependent upon the design of the dwelling.

Usage	*Annual energy consumption (GJ)*
Heating and cooling	64.44
Water heating	34.53
Cookina	15.42
Refriaeration	15.45
Appliances	7.67
Lighting	6.53
Other	13.26
Total	**157.30**

Table 1 Typical annual housing energy consumption

4.1 Nationwide House Energy Rating Scheme (NatHERS)

The Nationwide House Energy Rating Scheme rates the heating and cooling energy efficiency of a dwelling with a value from zero to five stars [9]. In at least one State of Australia, a four star rating is now mandatory, superseding the minimum insulation levels for walls, floors and ceiling. The dwelling rating takes into account the appropriate local climatic conditions, of which there are 27 zones in Australia. The NatHERS simulation software package predicts the temperature inside a dwelling 24 hours a day, 365 days a year, calculates the amount of energy needed to maintain temperatures within the desired comfort range and assigns a star rating.

5 Life cycle energy

The embodied energy of different types of dwelling construction and energy efficiency in the Australian Capital Territory have been compared to the annual operational energy as calculated by the Nationwide House Energy Rating Scheme. The basic dwelling was that of a single family house with changes made only to accommodate the differences between timber cladding, standard brick veneer and cavity brick construction and the specific requirements necessary to meet zero to five star ratings as defined by the NatHERS software. Many elements remained constant throughout the options; e.g. roof, windows, wall, floor and ceiling finishes, sanitary fixtures and plumbing, water supply, space heating, electric light and power. The ratings were increased largely by insulative measures (Table 2).

Starrating	*Timber*	*Brick veneer*	*Cavity brick*
0	No insulation	No insulation	No insulation
1	PLUS RI .O insulation to underside of floor, R2.0 entire ceiling	PLUS R1.0 insulation to entire ceiling	PLUS R1.0 insulation to entire ceiling
2	PLUS RI .5 to external walls	PLUS R0.5 to external walls	CHANGE ceiling to R2.5
3	CHANGE underfloor to RI .5, ceiling to R2.0, external wall to R2.5, PLUS external blinds, seal 85% of windows	CHANGE ceiling to RI .5, external wall to RI .5	PLUS RI .O to external walls
4	CHANGE underfloor to R3.0, external walls to R3.0. and ceiling to R3.5	CHANGE external walls to R2.0, ceiling to R2.5, ADD RI .O to around slab	CHANGE external walls to R2.0, ADD RI .O to ground slab
5	CHANGE to double glazing all windows, re-orient dwelling to north, seal downlights	CHANGE to double glazing all windows, ceiling to R3.0	CHANGE to double glazing all windows, ceiling to R3.5, ADD external blinds

Table 2 Insulative measures to achieve star ratings in a single family dwelling

5.1 Comparison of embodied and operating energies

Initial results show that

- it is not necessary to have heavy construction to achieve increases in operational energy efficiency for a dwelling (Figure 3, Figure 4),
- the timber dwelling required the greatest increase in embodied energy to achieve a 5 star rating (42% increase) from a 0 star rating (Figure 3),

- the largest incremental increases in embodied energy occurred when stepping up from a 4 star rating to a 5 star rating (Figure 3),
- conversely, very little additional embodied energy is required to raise the star rating from 0 or 1 to the next highest rating (Figure 3),
- the ratio of embodied energy to annual operating energy increased dramatically as the star rating increased mainly because of the rapid decline in operating energy (Figure 4), and
- the importance of embodied energy in a life cycle model of energy becomes significant (equal to 20 years of operating energy and 20% of life cycle energy for a dwelling life of 80 years) for 4 star rating and above (Figure 4).

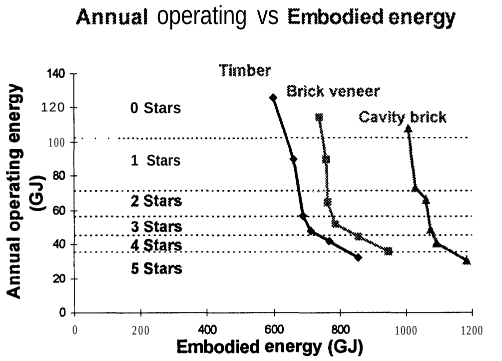

Figure 3 Annual operating energy as a function of embodied energy

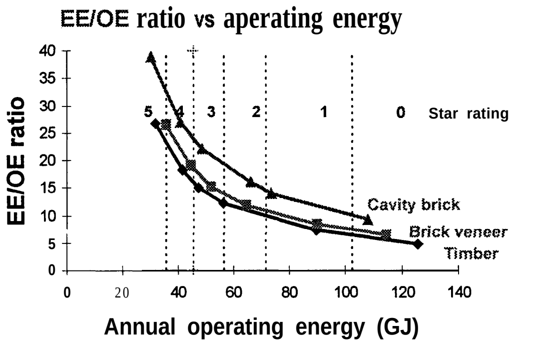

Figure 4 Embodied energy to annual operating ratio as a function of annual operating energy

6 **Uses**

The embodied energy model has been developed as an evaluative tool for assessing the comparative embodied energy impacts of alternative materials to assist in determining the overall environmental impact (as measured by embodied energy or CO_2 emissions due to energy use) of alternative design and building materials at the design stage of a building. It provides a designer with a measure of the total environmental impact of a building or component from a perspective never before undertaken.

Designers and quantity surveyors are familiar with the elemental cost planning approach to building de-composition and, as it is an accepted analytical approach to building design, the same approach facilitates comparisons between embodied energy impacts and building costs of elements of building, not individual materials. The effect of "trade-offs" should become apparent. For example, a particular insulating material may incur high embodied energy impacts in terms of product manufacture, but require little energy to install and maintain and it may enable greater energy savings to be achieved in the operation of air cooling or heating systems.

Embodied energy impacts are best studied at an early stage in the design process of buildings and should focus on the combinations of the main contributors to the totals for the building. The effect of using alternative materials on the total embodied energy and annual operating energy of a building, can most readily be investigated at this design stage, preferably before any major design decisions are taken.

The ability to perform any analysis work direct from CAD drawings is a relatively new concept and one that will probably be utilised more as systems are developed with more analysis and detailed studies. Likewise, the concept of embodied energy is relatively new and this program is one of the first to attempt to provide a simple and effective methodology for performing embodied energy calculations. The program is the first, as far as is known, to attempt to calculate quantities of every material in a building (rather than items which can be costed) and thus the first to estimate embodied energy direct from a 3D CAD drawing.

7 Benefits

The provision of fast environmental evaluations of embodied and operating energies and CO_2 of whole buildings is a major benefit in evaluation of alternative designs. It requires little additional effort by designers, architects and quantity surveyors to perform embodied energy and CO_2 calculations. The 3D CAD model also allows users to compare the embodied energy and CO_2 for parts of a building, if required.

This approach identifies the main contributors of embodied energy and CO_2, by element and material categories so that designers can concentrate on the areas where gains are likely to be most easily achieved and provides detailed material breakdown of building elements for other environmental assessment procedures. The various multi-level analysis options provide users with a highly flexible method for obtaining the data required for analysis and decisions.

The embodied energy total provides an energy value for the whole building on the same basis as operating energy for life cycle energy assessments and provides a method of assessing trade-offs between more energy intensive materials and less energy requirements for heating and cooling over the life of a dwelling.

There are a number of steps to be undertaken before a practical life cycle energy model can be made available to industry practitioners, and these steps include:

- development of the prototype embodied energy and CO_2 emission module to a commercial version, as has been done with the NatHERS software.
- expansion of the embodied energy and CO_2 database to cover construction energy and most materials and items commonly found in buildings.
- linking of the embodied energy module to the operational energy model in order to represent a total life-cycle (or ‘cradle to grave’) view of the energy impacts of dwellings.

8 Integration of evaluation methods

The embodied energy module in 3D CAD is an example of integration of a new analysis need (embodied energy) with an existing need (quantities of materials) based on an object oriented approach to specification of building items. Additional databases were created and additional analytical tools were developed to complete the integration. The effort required by users to apply such models is then only minimal. This is but a first step to implementing a life cycle energy model (and other applications) which includes the existing operating energy models.

9 Conclusion

Embodied and operating energy and CO_2 emissions are becoming important factors in the built environment and with the possibility of legislative requirements and standards, the ability to perform accurate calculations is essential. The prototype embodied energy software is the first example of a simple, yet effective CAD based tool to perform these calculations directly from quantities of individual components of a building. The complementary NatHERS operating energy model is an excellent example of a practical tool for analysis of an environmental impact of a dwelling. The two models both allow designers to undertake a sophisticated analysis on their designs and to compare alternative design solutions, quickly and effectively. There is an enormous potential for using 3D CAD based tools for analysis work, not only for embodied and operating energy, but for a range of environmental areas as well.

10 Acknowledgments

The prototype embodied energy software would not have been possible without the participation and guidance from a dedicated team of developers and researchers from the CSIRO Division of Building, Construction and Engineering in partnership with Cedar Enterprises, RMIT University and Wilde and Woollard and with financial support from the Energy Research and Development Corporation (ERDC).

11 References

1 Tucker, S. N., Ambrose, M. D., and Edwards, P. J. (1996). Evaluating embodied energy in construction using a 3D CAD based model. Embodied *Energy: the current state of play.* Deakin University, 28-29 November. (1 lp.)

2 Lawson, B. (1992). Capital energy costs of building and recycling of building materials. Proceedings of *Construction Beyond* 2000, Espoo, Finland.

3 Pullen, S.F. And Perkins, A. (1995). The analysis of energy consumption in the built environment. *Transactions of the International Symposium on Energy, Environment and Economics.* The University of Melbourne, November.

4 Tucker, S. N. and Treloar, G. J. (1994). Energy embodied in construction and refurbishment of buildings. *First International Conference on Buildings and Environment.* Watford, United Kingdom, 16-20 May. (8p.)

5 Pullen, S.F. (1996). Data quality of embodied energy methods. *Embodied Energy: The Current State of Play,* Deakin University, Geelong, 28-29 November.

6 Stewart, P.J., Edwards, P.J. and Graham, P. (1995). Measuring the energy used in the construction of residential housing. *ARCOM Eleventh Annual Conference.* (Association of Researchers in Construction Management: Salford)

7 Wilkenfield, *G.* (1991). *Greenhouse gas emissions from the Australian energy system. The impact of energy efficiency and substitution.* ERDC.

8 Department of Urban Services (1996). *ACT House Energy Rating Scheme manual.* (Planning and Land Management Division, Canberra).

9 NatHERS (1996). House Energy Rating Software for Windows (Addendum for ACT Climate).

the TWIN-model, an environmental calculation method as performance concept

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Abstract
(Interests, Interactions and Implementations of Sustainable Design and Constructions in The Netherlands)
GreenCalc is a computer programme, which yields insights into the environmental impact created by the construction and exploitation of a building. This gives the initial impetus to the development of environmental performance standards. GreenCalc currently consists of four modules, namely:

- Materials usage during construction and maintenance
- Energy consumption during exploitation period
- Water consumption during exploitation period
- Liquid assets produced during exploitation period.

A module to calculate used volume of space by buildings is being developed.
The environmental impact created is expressed in environmental costs, which means it can be transferred between modules. Thus, a less environmentally favourable choice of materials can be compensated for by an exploitation method, which is more energy efficient.

The materials module is based on the TWIN model, a method which overcomes the limitations of current life-cycle analysis studies (LCA studies). The TWIN model is based on a 'double-layer' system. The first layer is an incomplete quantitative layer which uses all LCA results which are available (naturally just the quantitative data). However, the first layer is incomplete and contains 'gaps'. For example, the regional impact cannot be expressed in quantitative terms, although a fairly large amount of information is already known about it. The second layer was developed to take care of this; it consists of a completely qualitative system. Together, the two layers give the most accurate result which can currently be obtained.
In addition, the TWIN model can give an environmental assessment and a separate assessment of the health aspects. Since health is becoming a more and more important item, it makes sense to make it easy to gain insights into it here.
This contribution dovetails with the contribution by George Ang regarding Performance Concepts and with the contribution by Marcel Dewever regarding Environmental Costs.
Keywords
Environmental impact, LCA, quantitative-qualitative, performance standards, environmental costs, health, computer programme.

Introduction

The publication in 1989 of the Dutch *National Environmental Policy Plan,* based on *Our Common* Future, made it clear for the public that the building industry ranks among the worst polluters. The *State of the World* 1995 shows that approx. 50% of all the world's dust-pollution flows are directly or indirectly linked to building activities. The Dutch report Care for *Tomorrow* reveals that the quality of the in-door environment is hardly healthy enough for living. In principle this has two causes; on one hand the ever enduring increase of chemicals in building, hereby enabling a greater efficiency in building, and on the other hand the increasing in-sulation of buildings with poorer ventilation performance resulting in an undesir-able build-up of moisture and toxics in interior spaces. Also *see Toxics in Buildings* by the author.

By opting building materials with a lower environmental impact and health hazard than those currently in use opt, an essential contribution can be made towards a sustainable development.

Need to gain insights at an early stage in the process

In the development process for a building, it is important that insights into the envi-ronmental impact of the building be obtained at as early a stage as possible, pref-erably when the very first sketches are made. The environmental impact of a building is primarily determined by materials usage. High-quality data about con-structions' environmental impacts can only be obtained from LCA studies, which require very detailed data.

There is a contradiction inherent between gaining insight at as early a stage as possible and having access to as detailed data as possible. This problem can only be solved by the development of a computer programme. This is why GreenCalc was developed, which can be used from the beginning of the design process up to and including the last working details, which makes it a good steering tool. Cur-rently, GreenCalc consists of four modules, namely: a materials module, an en-ergy module, a water module, and a liquid assets module. A module on usage of space is being developed.

Henceforth, the emphasis will be on the intrinsic background to the materials module, based on the TWIN model, which I recently obtained my doctorate with a thesis on.

LCA-method

In both reports *Environmental-orientated life-cycle-analyses of prociucfs, Manual and Backgrounds* in October 1992 an unambiguous assessment-method is de-scribed. It mentions the steps in order to achieve an environmental-consci-ous life-cycle analysis (LCA). In this method first all the interventions are stated, then the effects on the environment and our health. The actual assessment is based on the effects on the environment. These reports proposed a methodological ap-proach that has eventually become an international standard.

Due to the fact that the LCA-method has not fully matured yet, there are as still "gaps" or shortcomings in the method, especially considering the development of data. In this method health aspects are not fully acknowledged, the section on environmental impact is not worked out in sufficient detail, and a method of weighing data in order to reach a final assessment is lacking.

In practice only quantitative (measurable) effects are used in LCA-studies, thereby ignoring other valuable data in the final assessment. Therefore it is actually not possible to draw comparative conclusions for LCA-studies, while the agents in building are greatly in need of more reliable data considering environmental aspects than the well-known “selection-lists”.

Purpose of the TWIN-model

The purpose of the TWIN-model, my doctoral research, was to develop a method which, although based on the currently available data, extends beyond the existing intuitive or argued methods in order to compensate the lacking quantitative data based on measurements. Use can be made of data available from research and literature, including previously conducted life-cycle analyses. In the absence of reliable data, in order to obtain a balanced full life cycle view, the method allows for additional estimates, which provide insight and can be applied recurrently. Due to this open character, adaptation and adjustment will be possible at all times, hereby complying with ever changing process circumstances.

In addition, this presents the possibility of reversing the onus of proof. It will not be the task of the researchers to prove that a material, product, or building component impacts the environment or affects health, but rather the task of the manufacturer to show that this is not the case, or at least to a lesser extent than assessed (worst-case-analysis). The method can process both quantitative and qualitative data.

The classification model that is developed is capable of predicting environmental impact and health risks within certain defined performance levels.

Subgoal in the TWIN-model was to resolve a number of problems in the present LCA-studies, enabling clear comparisons between building constructions and eventually whole buildings.

assessment also based on health

In the present LCA-method the aspect of health is far from being sufficiently appreciated. In order to have this aspect fully acknowledged the LCA-method has been extended by incorporating health criteria. The extension is developed in the form of a separate module so as not to deviate too much from the standard LCA-method.

elaboration of impact in LCA-method

The section on impact has not been elaborated on in the present LCA-method and is therefore mostly not considered as an assessment criterion. Assessments can very well turn out differently if the factor impact is incorporated.

> In a recent LCA-study turned out that the winning of new sand more favourable was than using recycled sand. In this study the impact on the landscape was not incorporated. Therefore the winning of new sand had less environmental impact on the landscape in the case of the winning of new sand had been incorporated, then the final assessment might have turned out differently!

determination of weight-factors

In order to achieve a final assessment it is necessary to apply weight-factors for the step of defining classification. A set of weight-factors has been developed; this ‘step is indicated in the LCA-method, but has not been worked out in more detail. Heijungs states on this point in *Environment-orientated* life-cycle-analyses of *products*: “In the case of a quantitative environmental-criteria-analysis the various environmental effects are summed up after multiplying each effect with the corresponding weight-factor. The question who judges the environmental effects or who even should determine the weight-factors is not a problem of methodology, but of practical political nature."

As indicated in The tco-indicator 95: "A LCA must lead to a definite unambiguous result and not to a number of contradicting effect-scores, that cannot be interpreted by a designer (and many environmental experts)."

It is therefore important to determine the relationship between the various environmental aspects. In order to achieve this, weight-factors have been developed within the TWIN-model, thereby making it acceptable to relate the various environmental aspects to each other.

Speaking in terms of a metaphor we are talking about a method to compare the various fruit in a basket.

incorporating quantitative and qualitative data

Because it will take years yet before the necessary data will be available in the quantitative sense, it is necessary in the interest of a complete LCA-profile that data that are not quantitative be expressed in a qualitative sense. Again the LCA-method provides in this as Heijungs states: "In a number of processes not-quantifiable aspects are of importance. These should also be mentioned: the format explicitly provides for this kind of data". Nevertheless in practice not-quantifiable aspect are left out in the present LCA-studies, leaving a distorted impression. The TWIN-model explicitly provides in the possibility of relating quantitative and qualitative data in one model.

Description of the TWIN-model

The model consists of two parts, namely a quantitative part and a qualitative part. This last part consists of two matrices, one for an environmental assessment and one for a health assessment. Due to the fact that these pairs are to be considered as twins, the whole is called the TWIN-model.

shifting between layers of systems

A complete qualitative system has been developed that can be substituted by a quantitative system for each criterion; a system that closely links to and even covers to a high degree the LCA-method of the CML. Hereby two complete systems have come into being, of which the quantitative system represents the highest degree of accuracy and the qualitative system covers the area where no quantitative system data exist as yet. Only the combination of the two systems together reveal the full spectrum of environmental and health impacts.

The whole model can be considered as a layered system, in which the quantitative and the qualitative layers can be exchanged. When more knowledge is eventually developed in the quantitative sense, then there will be a shift towards the quantitative system. In the beginning there will be more knowledge in the qualitative system.

performance scale of qualitative data

The possibility of making an objective assessment of the environmental qualities of a building material, building product or building component is very limited. Much quantitative data is still lacking, so assessment can only be based on quality for the time being. In order to ease the subjective aspect, being typical for the qualitative system, the environmental and health criteria have been divided into sub-criteria. For each sub-criterion a performance description has been made in various levels (see supplement performance scales.) Certain environmental impact

			raw materials extraction	material production	building construction	use and maintenance	building demolition	waste processing
2	HEALTH CRITERIA / HUMAN TOXICITY							
2.1	physical agents							
2.1.1		electromagnetic fields •						
2.1.2		electrstatic fields •						
2.1.3		static magnetic fields *						
2.1.4		radon and radioactivity •						
2.1.5		moisture balance *						
2.2	chemical agents							
2.1		solid chamical agents •						
.2.2		liquid chemical agents •						
.2.3		gaseous chemical agents •						
21.3	biological agents							
.3.1		bacteria *						
.3.2		viruses *						
.3.3		parasites *						
.3.4		fungi *						
2.4	ergonomics							
.4.1		lifting •						
A.2		working posture *						
2.5	safety							
.5.1		accidents *						
.5.2		shielding/protection *						

the health-criteria of the TWIN-model as a matrix

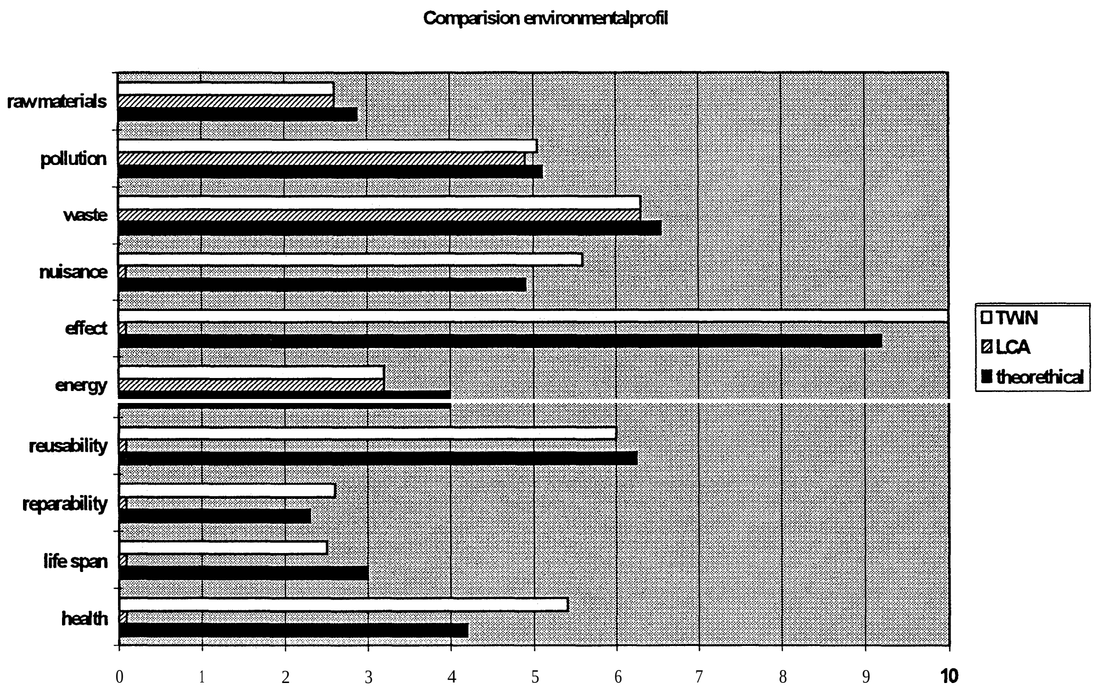
A major advantage of the TWIN-model is the possibility of not only comparing building materials, but also components and even whole buildings. Other methods cannot as yet offer this possibility. In addition it is possible to achieve integral assessments based on the best available data from other research sources (quantitative and qualitative data).

GreenCalc, an environmental calculation method for buildings

A computer programme has been developed in collaboration with market players, based on the TWIN model presented here. This programme is now available and contains an extensive database, which includes all the common types of building/construction, assessed according to the TWIN-model method, which is now covered by a patent.

In contrast to the method used in the TWIN-model, the results arrived at using the GreenCalc programme are expressed in environmental costs. This method dovetails better with the management decision-making culture: managers always think in terms of money and in particular are responsible for their own budget. The budget 'hole' or shortfall is much closer to home than the hole in the ozone layer. This is why our GreenCalc programme has turned the hole in the ozone layer into a hole in the budget. The link to environmental costs is arrived at by taking the available quantitative data as kg-equivalent CO_2 pollution and multiplying it by the costs of preventive and/or corrective measures for one kg of CO_2. These costs can be quantified very accurately within certain limits. In the case of qualitative data, comparisons are used. In order to be able to determine the regional impact,

corrective measures carried out are assessed and used to determine what the environmental costs for the correction of the environmental impact are.
Using this method means that weightings are no longer needed, as this function is taken care of by the expressing of all factors in money terms. This also means that the individual GreenCalc modules can be weighed up against each other. For instance, working with natural ventilation reduces energy consumption, but leads to the building having a greater bulk. Does the environmental benefit of the energy saving compensate for the negative environmental impact of the additional usage of materials? It is also possible to compare the retaining of the existing building against the construction of a new building and to work out the size of the environmental gain.
Finally, GreenCalc now makes it possible to translate the list of requirements for the building into environmental costs. These environmental costs then become the construction budget, which data can periodically be compared with. This means that environmental performance requirements can be formulated in advance and continually tested during the construction process to see whether they are being achieved.
I hope that Mother Earth will benefit from it.



in this diagram possibilities of the TWIN-model are shown, the lower line is the theoretical possible environmental impact caused by the product (this environmental impact might be know first in 50 years), the second line shows the results of a LCA-study, with a limited number of environmental aspect cautiously approached, the upper line shows the possibilities of the TWIN-model, LCA-results are included and the not available dates are added caused the worst-case-analysis; looking at the total, the picture becomes more c/ear than when working with only the LCA-results

SUSTAINABLE DEVELOPMENT BUILDING DESIGN AND CONSTRUCTION - TWENTY-FOUR CRITERIA FACING THE FACTS

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Abstract

The paper reports on the use of a set of twenty-four criteria established in 1996 covering the whole life cycle of a building. Four types of building (house, apartment block, off6ice block, supermarket) of either concrete or lightweight construction, in a rural, suburban or inner city setting, have been analysed.

Each of these alternatives was broken down into 'functional' components (site suitability, structure, exterior walls, indoor walls, equipment (HVAC, specific electrical circuits) and finishing, each using the most common relevant technologies.

Each alternative was screened through the twenty-four criteria, with a matrix approach to handle the large quantity of data. The results are tabulated in three matrices covering the object (building, technology and architecture), process (design, construction, operation and end-of-life), and interactions (environmental impact of building, relationship with townscape and socio-economic dimension).

The first lessons learnt from this work are presented.

Keywords: Sustainable development, research and development

1 Introduction

While sustainable development contains all sorts of ambiguities and sources of confusion, the general concept it embodies is nevertheless vital for the future of the planet, our society, and, lower down the scale, the building profession.

Greater importance must be given to long term prospects in the daily decisions involved in new building and to the whole life cycle of the finished structure, including what will happen to the site when it is eventually demolished.

The forward planner must identify the major challenges that will confront the building. This idea was the starting point for the working group formed by the Club BatiVille, made up of CSTB, ADEME and Dumez with assistance from Cabinet Space, to undertake a methodological approach to consider the building from the standpoint of sustainable development.

This purposely general and systemic approach looked at socio-economic development, the environment, resource use, and the waste generated.

The methodology comprises four mains steps:

- Analysis of mutual issues concerning both the building industry and sustainable development.
- Theoretical input to conceptualise sustainable development as applied to the building industry, leading to a set of characterising criteria.
- Instrumentation, specifying indicators of whether the criteria have been met, and, where applicable, suggestions for initial research and development vectors.
- Evaluation and validation by practitioners to stabilise the concept and propose concerted research agendas.

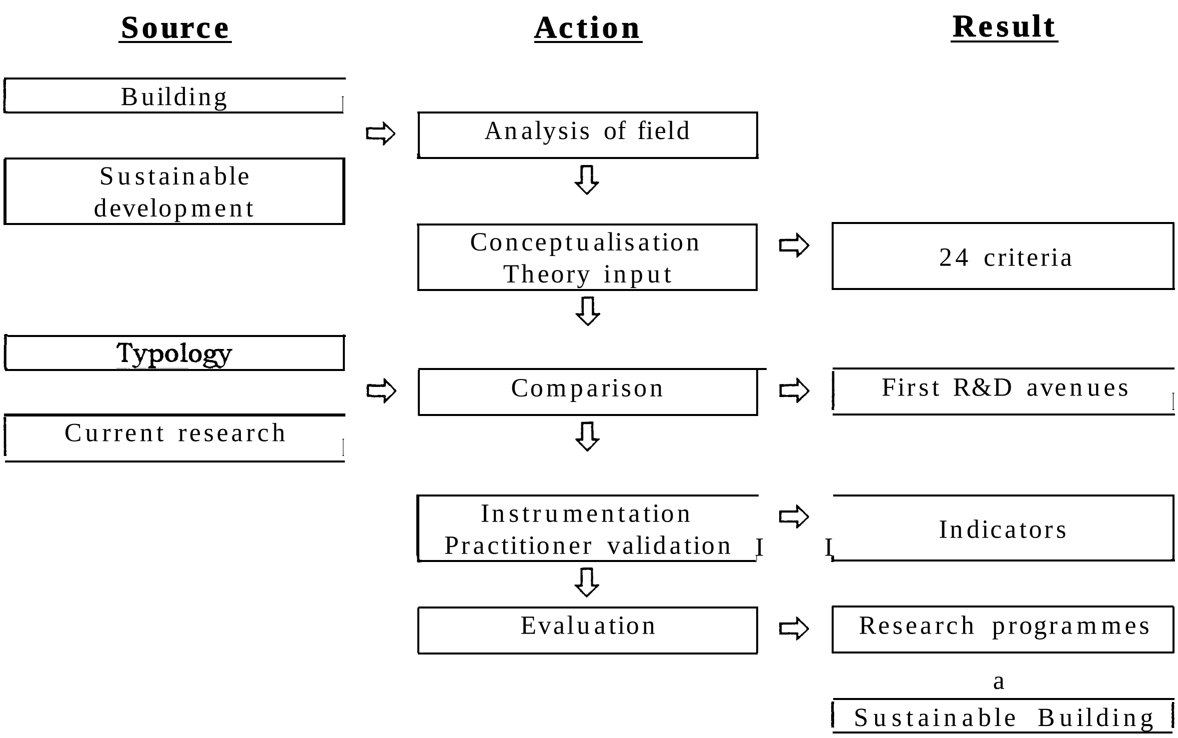

Table 1: Sustainable Building Methodology

The first step produced a set of twenty-four criteria (see below). A further step was taken in recent months to make progress in instrumenting these criteria and find those for which for which workable indicators already exist, those for which substantial on-going work promises tangible results within the foreseeable future (sometimes at the cost of broadening and refocusing goals) and those for which lack of currently available or pending knowledge (at least on the part of the members of the group) makes further research necessary to evaluate or invent pertinent indicators.

This paper describes this analytical work and resulting proposals for action. It is also hoped it will incite the scientific community and professional stakeholders to debate the initial results of our confronting the twenty-four criteria with concrete tools for their application.

2 Analytical Review of Criteria

The following list shows the main opportunities for improvements as indicated by looking at available technologies for each alternative examined, in the light of these criteria.

1 - Capability of fulfilling required function
- Generalise planning and design performance approach by specifying referents
- Improve home safety
- Evaluate health impact of building goods and materials and eliminate those known too be toxic or dangerous
- Improve indoor air quality and develop filter and purification equipment for buildings exposed to outside sources of pollution at urban sites
- Improve external noise mitigation

2 - Capital impact
- Promote whole life cost concept: eventually presupposes combining capital costs and time-dependent costs, including demolition, by broadening the approach to cover financial costs and internalisation of external (environmental, urban, etc.) costs
- Analyse the value of each of these items in order to optimise them

3 - Implementation logistics
- Include construction constraints and potential services offered by builders at the earliest project planning and design stages
- Encourage new products making construction easier (assembly connector design, etc.)

4 - Working conditions
- Stress clean jobsite approach
- Develop handling and lifting gear to reduce manual labour and improve safety at work

5 - Impact on personal pride
- Encourage quality assurance approaches to give workmen a sense of personal responsibility and make work more rewarding
- Improve circulation of information by tapping potential of new communications technologies

6 - Disturbance from construction sites
- Improve control of incoming supplies to jobsite and outgoing waste (packagings, waste sorting and re-use)

- Reduce waste at source: simplify product ranges, encourage re-use and returned packagings, reduce unnecessary packaging
- Reduce noise, dust, waste water and other nuisances to residents

7 - Raw materials resource use

- Develop methods of aggregating product life cycle analyses to have a better insight into use of raw materials resources in the building industry
- Encourage recycling

8 - Energy resource use

- Optimise energy efficiency of products, processes and buildings, and recover free inputs
- Make optimum use of locally-available renewable resources
- Develop and instrument product and construction process life cycle analyses.

9 - Lifespan and strength

- Build data banks on lifespans to integrate them into whole life cost approach
- Correlate natural ageing and accelerated ageing

10 - Optimised maintenance

Devise a description of the completed building designed around operating and maintenance requirements

Develop performance sensors (ageing and loss of performance)

Develop comprehensive, accessible preventive maintenance methods

11 - Consumption and waste

Improve knowledge of consumption and waste trends (water, municipal solid waste, garden waste, etc.)

Expand R&D on clean, low-consumption technologies (solid waste, air conditioning and other uses) to reduce running costs, resource use and pollution

12 - Costs of access to communal services

Develop tools by which urban project development methodologies can include for constraints and opportunities offered by business location

Develop methods of optimising capital cost of utilities

Investigate utilities cost structure in order to optimise pricing

13 - Control of movements

Adapt simulations to optimise movements in terms of safety and convenience

Improve quality of way in which circulation are dealt with

14 - Immaterial movements (control signals, information, communications)

Develop information transmission technologies in-building and between buildings and surroundings (power systems, low current systems, remote control, etc.)

Imagine new uses

15 - Inter-modal transport

Develop tools for optimising parking capacities to suit means of transport available near buildings

Investigate opportunities offered by virtual offices and teleworking

Investigate relationship between workplace and mobility (home-work-shops-leisure) and derive optimisation tools

16 - Capability for incorporating neighbourhood services

- Review expectations of occupants, their needs, and types of neighbourhood services that can be incorporated in buildings
- Examine construction techniques that really integrate such functions

17 - Avoided social costs

- Investigate social needs and means of providing for special needs: the old, handicapped, children, ethnic groups, etc.
- Investigate social issues and relationships as affecting design of buildings and/or urban districts

18 - Impact on heritage

Investigate spatial segregation and its social and economic consequences

Improve architectural and landscape representations of buildings and open spaces (townscapes, etc.)

Determine acceptable levels of nuisance to residents with reference to changes in community expectations: noise, sunlight, proximity, etc.

19 - Impact of building on environment

Development platforms for integrating tools for simulating and evaluating impact of building on its environment

20 - Capacity for change

Develop connection systems for indoor pipe and cable that facilitate replacement of obsolete technical equipment and ability to accommodate new products

Develop modular components

Encourage integration of basic functions in indoor and/or external walls (analysis of value, functionality, ergonomics, etc.)

Develop loadbearing structures suitable for convenient, inexpensive changes in indoor arrangements (removable and movable partitions, etc.)

21 - Capacity for new final use

Develop connection systems for indoor pipe and cable that facilitate change of use of premises

Develop, where possible, modular structural components designed for easy assembly/disassembly to permit convenient, inexpensive changes of use of indoor premises

Develop integration of basic functions in indoor and/or external walls (analysis of value, functionality, ergonomics, etc.)

22 - Opportunities for improving performance

- Simplify component ranges and standardise connection systems
- Improve installation/removal ergonomics and accessibility of installations, systems and components
- Develop renovation and maintenance systems that do not inconvenience occupants (insulation from outdoors, central boiler, distributions to communal facilities, etc.)
- Develop products and components of high environmental quality specifically suited to building improvement and renovating

23 - Ease of demolition

- Develop materials suitable for easy sorting
- Develop methods for making pre-demolition audits and organising the work

24 - Removal

- Develop construction systems that are easily dismantled (dry assemblies, lightweight materials, modularity, etc.)
- Develop quick methods (saving time)
- Design intermediate storage systems suitable for demolition sites (mobile waste disposal units, etc.)

- Develop systems of marking products for easy recognition during demolition

3 Conclusion

Three remarks are called for at the conclusion of this manifestly operational exercise.

1. The construction industry must make a significant effort if it is to arrive at its sustainable development goals. Expressed differently, our lifestyle offers great potential for progress towards balanced, effective development.
2. It is suggested there should be an international observatory of construction technologies in the light of these twenty-four eminently practical criteria, since they provide a convenient framework that can be shared by all professionals.
3. Apart from this analysis of potential improvements, and looking at processes and products in the light of this framework, it appears that there will quickly emerge two inevitable trends, (i) concurrent engineering will become essential to improve liaison between the various parties involved, and (ii) there will necessarily appear the concept of the autonomous 'self-contained' building, i.e. one which minimises energy exchanges with its environment.

References

1. Angioletti, R., Gobin, C. & Weckstein, M. (1996) 24 critères pour un développement durable. *Cahiers du CSTB*
2. Angioletti, R., Gobin, C. & Weckstein, M. (1997) Twenty-Four Criteria for Designing and Constructing Buildings on Sustainable Development Principles. *CIB Task Group* 8

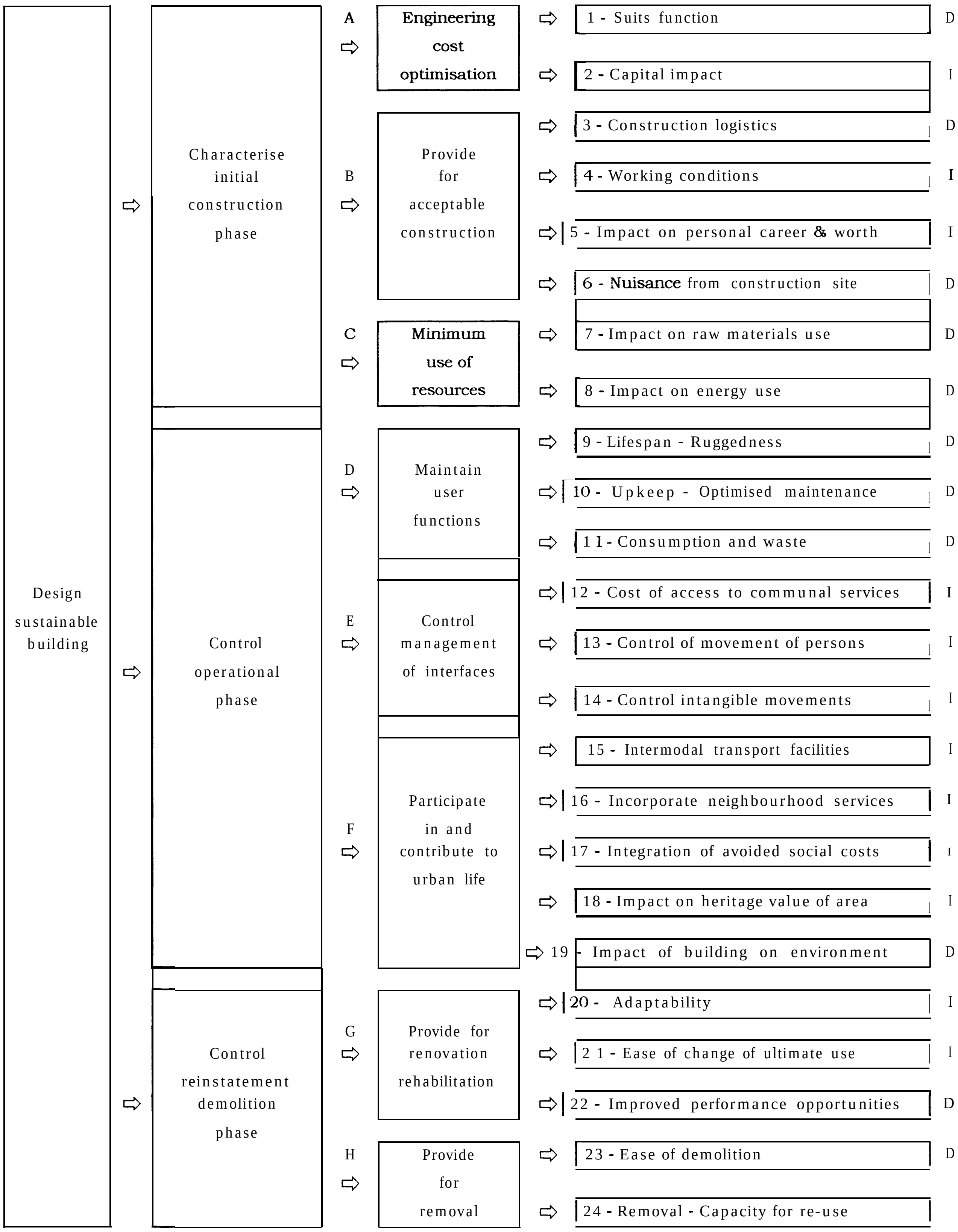

Figure 2: Sustainable Building Tree

Strategies for change - understanding sustainable development from a construction industry perspective

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Abstract

The construction industry, along with all other industries is being challenged to become sustainable. The industry is currently searching for a definition of sustainability which it can apply to its activities. However, sustainability is multi-faceted and infinitely variable in its interpretation. This paper, without making a definitive statement on sustainability, sustainable development or sustainable construction, considers the factors which will shape and influence the construction industry in the future. The paper:

- explores the developing framework for sustainable development
- considers some of the likely impacts on the industry
- sets out four strategies for change and development that the construction industry could adopt

The paper asserts that sustainable development means change and that the construction industry should search for solutions which help create an industry-wide "Strategy for Sustainablility". Whilst for many construction businesses such a strategy may well appear to be impracticable and too far from their current trading reality, there is evidence from the UK construction industry that commercial practices such as Partnering and Value Management are providing a platform for the development of sustainability strategies.

Further evidence from current CIB research projects suggests that the industry will have to adapt to new construction markets with environmental dimensions which will be driven by a mixture of political and market forces, requiring products which respond to genuine need and concerns.

The findings presented in the paper are drawn from work carried out by the author for: CIB Working Commission W82; the UK Government's Office of Science and Technology (OST) and Department of Environment, Transport and the Regions (DETR) and the Environment Committee of the UK's Chartered Institute of Building (CIOB) which addresses the needs of construction management professionals.

Keywords: Sustainable development, strategies, components and drivers of change

1.0 Introduction

The construction industry has a substantial impact on our society. It shapes our townscapes and provides us with shelter, work environments and leisure facilities. The industry and the resulting built environment impacts upon the natural environment over a long period of time and sometimes with devastating effects on local habitats and ecological systems. The construction industry, along with all other industries is being challenged to become sustainable. The industry is currently searching for a definition of sustainability which it can apply to its activities. Sustainability is, however, multi-faceted and infinitely variable in its interpretation. This paper, without making a definitive statement on sustainability, sustainable development or sustainable construction, sets out some of the key factors which will help shape and create a sustainable society and explores the options and likely impacts for construction.

Sustainable development means change and that the construction industry needs, in response, to search for solutions which move towards an industry wide "Strategy for Sustainablility".

The impact of this change, upon organisations and institutions, is currently difficult to define. For example, how can a company reconcile its responsibilities towards shareholders with issues such as community employment and welfare? How can that same company justify the inclusion of third-party interest groups in it's decision making process? However, based on current international research carried out by the CIB Working Commission W82 (Construction Futures), it is expected that industry will be required to address exactly these issues, giving corporate responses which go beyond their organisations' normal boundaries of activity and often beyond their normal areas of expertise.

2.0 The challenge for the construction industry

In the UK, the Latham report [1] has highlighted the need for change and improvement in the construction industry. The demand for construction which is "sustainable" places further pressure on the industry. The challenge for the industry is to identify new and innovative practices, technologies and ways of working which satisfy the need for a modern, competitive, efficient, responsive and socially responsible industry.

How can the industry transform the demand for change into an opportunity, to create and access new markets, find innovative responses which satisfy traditional industry demands and the new societal demands for sustainable development?

Unfortunately, the industry has to overcome many barriers to achieve this state. It is risk-averse, as are the majority of its clients, it is highly regulated, competitive, fragmented and dominated by contracts which regulate the involvement of the client in the construction process. These same contracts assign liability for failure onto the suppliers and providers in the industry over a long timespan.

3.0 Developing understanding - the framework for sustainable development

This paper does not attempt to define sustainable development; there are many definitions produced by others. Whilst not exhaustive, those definitions listed below indicate the range of expectations which various sectors of society have for sustainable development and what the expectation is for businesses. For example:

"........... to meet the needs of the present without compromising the ability of future generations to meet their own needs."

The World Commission on Environment and Development (The Brundtland Commission), Our Common Future. Oxford: Oxford University Press, 1987, p43

"Our vision is of a life-sustaining Earth. We are committed to the achievement of a dignified, peaceful, and equitable existence. A sustainable United States will have a growing economy that provides equitable opportunities for satisfying livelihoods and a safe, healthy, high quality of life for current and future generations. Our nation will protect its environment, its natural resource base, and the functions and viability of natural systems on which all life depends. "

The President's Council on Sustainable Development, Feb 1996.

"The central purpose of a sustainable enterprise should be to promote "sustainable livelihoods" through the creation of jobs and resulting purchasing power, and the production of products and goods and services that are needed to better the lives of people"

Arun Kumar, Development Alternatives, Network Conference, Boston 1993

"Business should cooperate with government and society to identify problems, articulate the goals, search for solutions, and implement measures. Business should be both profitable and environmentally sound"

Robert Campbell, CEO Sun Company, Boston 1993

Evidence of the breadth of issues to be considered can be gained from many sources including statements of intent regarding sustainable development from around the world. For example: The US Presidents' Council on Sustainable Development [2] makes 16 statements of belief which cover broad ranging issues such as:

- Economic growth - jobs, productivity, wages,
- Protection of the environment - monitoring, legislation,
- Individual, institutional and corporate responsibility, commitment and stewardship.

Furthermore, statement 16 in this US publication is a good illustration of how other issues such as education, public participation and social responsibility will be integrated into all aspects of business and governance. It says "Citizens must have access to high-quality and lifelong formal and informal education that enables them to understand the interdependence of economic prosperity, environmental quality, and social equity - and prepares them to take actions that support all three."

An indication of policy in the UK can be found in a report "Indicators of Sustainable Development,"[3] published in 1996, by the UK Government's (then) Department of

Environment. This presents two basic aspirations of society: to achieve economic development to secure rising standards of living both now and for future generations; and to protect and enhance the environment now and for the future. Four main aims were proposed in this document:

- to maintain a healthy economy, promoting quality of life and protecting human health and the environment in which all pay the environmental costs of their decisions
- the optimal use of non-renewable resources
- the sustainable use of renewable resources
- minimising damage to the carrying capacity of the environment and the risk to human health and biodiversity from the effects of human activity.

Following recent Governmental changes in the UK, wider social issues are also being included in this strategy. The remit of the former DOE has been broadened. The new Department of Environment, Transport and the Regions (DETR) has issued a consultation paper on the UK sustainable development strategy reflecting a more coordinated and integrated response to the major components of sustainable development.

Agenda **21,** stemming from the Rio conference in 1992 is placing the emphasis on local, community action on sustainable development. It aims, at community level, to:

a integrate consideration of social, economic, and environmental conditions
a increase public participation and partnership, and
a implement long term strategies for continuous improvements in the community

Whilst these aims have been slow to come to fruition with so far little, if any, impact on business, it would appear that measures are being introduced which will overcome many of the institutional barriers which have impeded progress so far. In a review of Agenda **21,** Dodds [4], lists actions which are explicit about the involvement of businesses, such as:

- setting up a representative, multi-sectoral planning body or "stakeholder forum" as the co-ordinating and policy group for developing and monitoring a long-term sustainable development action plan
- implementing a consultation programme with community groups, NGOs, businesses, churches, professional groups and unions to identify proposals and priorities for action
- setting up monitoring and reporting procedures which hold the local authority, business and households accountable to the action plan.

4.0 Likely impact on the industry

This broadening of societal values and interests challenges the motives and values which have previously driven growth and development and which have previously defined industrial success. Dodds [4] proposes that an industrial perspective of sustainable development is built upon three pillars:

- economic growth
- ecological balance, and
- social progress

He proposes that industry's contribution to sustainable development comes through "eco-efficient" leadership, which can be more, or less, effective depending on the trading framework in which each industry operates.

It is clear that construction businesses will be expected to integrate into, and consider more fully, the issues valued by others at national, regional and community level. The W82 research project: "Future studies in sustainable construction", looking at the construction industry in the year 2010 suggests that the industry will need to respond to the "genuine needs and concerns" society and environmental concerns such as toxic substances, energy and water conservation, water and air pollution; and the integration of environmental actions into community and economic benefits. The study also suggests that changes in regulation, planning legislation and the demand for a life-cycle approach to design will impact on working practices.

5.0 Strategies for change

For many in the construction industry the components of sustainable development pose unfamiliar challenges. Many of the issues, often conflicting in themselves, are not considered in the current decision making process. Typical future concerns for the industry to address will be:

- who are the stakeholders in any decision making process - are they partners or detractors?
- what are the areas of risk and security?
- which construction activities contribute to sustainable development and which are in conflict?
- what are the market potentials and competitive threats?

For its part, the industry needs to adopt a strategy for change to work towards achieving development which is sustainable. The Greening of Industry report [5] lists four strategies for change which industry can take and which appear to be applicable to construction businesses. They are:

1 The defensive strategy - complying with regulation

This is a typical response from organisations in the construction industry where quality is governed by regulations. Typically, the cost of the environmental component in an industrial activity is counted as a cost of compliance with regulation and minimum standards. Often, the cost of non-compliance is the primary motivator to make improvements and so to reduce the environmental impact of industrial operations. For some the solution might be to find an environmentally less sensitive site or to conceal the impacts altogether. Typically, in organisations which follow this strategy, there will be low levels of environmental awareness and understanding.

2 The offensive strategy (beyond compliance) - development of environmentally friendly products, or going beyond compliance for competitive advantage.

In the service sector particularly, the environmental component of a product or service can be portrayed as a market benefit, adding value to its clients and customers. BREEAM [6] is an example of an environmental quality standard which has proved to add value and to provide market benefits for its users. The quality standards required to achieve high BREEAM ratings are above those required by law and the users (customers) of BREEAM-rated buildings identify many benefits beyond the normally accepted financial criteria. BREEAM is also valuable in illustrating the benefit of partnership, recognising and incorporating the needs and concerns of a wide range of users and stakeholders in the project under consideration.

Improved quality and customer focus can be identified as key components required to move from a "defensive" strategy to an "offensive" strategy. Quality and customer focus are also common components for the cultural change which is being sought in construction in the UK as a result of the Latham review. [1] There is thus a close relationship between the requirements on industry to deliver improved environmental and commercial objectives.

3 Eco-efficiency strategy - tries to identify win-win solutions by reducing environmental impacts and costs; includes concepts such as total quality environmental management and industrial ecology

This strategy goes one step beyond the offensive strategy and builds in a win-win outcome for supplier and client. There are examples of this response where supplier and customer collaborate to provide mutual benefit over and above the normally accepted contractual provision. " An important aspect of eco-efficiency strategy is its service provision." " Value enhancement must be sought through focusing on providing the service connected to their products to customers instead of selling as much product as possible." [5]

To succeed this strategy requires understanding on both the supply and demand side. Examples of partnering in the UK construction industry typify the approach required with examples of success and failure depending on the "attitudes" of all parties.

Dodds [4] identifies three components of this strategy:

- eco-efficiency, and
- leadership - which he describes as having vision, being proactive, transforming organisations and people.
- effective and innovative use of technology

Once again, these are issues common to the developments taking place in the UK construction industry as a result of the Latham review.

An example quoted recently [W82 Conference, Hungary, October 97] was a carpet manufacturer in the USA who contracted to provide a "carpeted area" throughout a building for an agreed period of time and to take back the carpet at the end of its useful life, when it would be recycled. The key step towards environmental improvement in this case was the provision of a service; rather than sale of product. Benefits included:

- for the client - quality products appropriate to location, elimination of waste materials, maintenance free provision, free replacement in heavily trafficked areas leading to consistent image and condition;
- for the supplier - long term contract, reduced waste, reduced manufacturing costs using recovered carpet material, improved environmental management performance.

Key components required to move from the offensive to the eco-efficient strategy include: the valuing and costing of environmental impacts; and identifying and valuing the full cost of development, over time, for all stakeholders.

4 Sustainability strategy - focusing on new and emerging partnerships between business and other stakeholders

Finally, we have the most advanced strategy, requiring an understanding and tolerance of complexity. It is likely that this strategic response will be achieved through decision makers adopting new values which reflect the aims, objectives and aspirations of sustainable development. For businesses used to short time horizons with defined, discreet client groups and markets, the risk of including and responding to the range of stakeholders and potential "clients" may be too high. What shape might the sustainable business take? From a range of policy research projects, there are indications that sustainable business will be more holistic, systemic and integrated [7]. Core values are likely to include [5]:

- "Wholeness" - understanding and accepting the system relationships between industry behaviour and its impact (usually known as the externalities in economic theory). This means taking responsibility for the impact of the business, so recognising that businesses do not operate in isolation to their surrounding environment. This approach leads to a shared responsibility and unity between the business and its community.
- "Care for future generations" - where a "future generation" representative may be included in the boardrooms of industry to challenge their time horizon for decision making, requiring more emphasis on whole life costing and long term impacts. The business takes responsibility for the impacts of its process but extends this over time
- "Smallness" - utilising small work teams, defining responsibility at the lowest level possible, requiring an ability to attend to detail "at the coal face", with increased ability to respond flexibly and innovatively.

The change from eco-efficient to sustainability strategy perhaps poses the greatest challenge to construction businesses. However, there is evidence (partnering, etc) to suggest that changes in working practice are taking place in the construction industry to bring about partnerships, shared ownership, shared risks and benefits.

6.0 Conclusions

Sustainable development from a construction industry perspective undoubtedly means change. For an industry which is inherently defensive the prospect of, and opportunity for, positive change is not always apparent, particularly in the context of the complexities of sustainability. This paper has explored the requirements of a sustainable society and the likely components of sustainable development. There is recognition that many of the issues are new to business. They are often referred to, by business and researchers alike, as "fuzzy" issues [8]; they extend the boundaries of normal business considerations. The paper has set out four strategies for change which industry can adopt, asserting that change should be away from "defensive" strategies progressively towards, "offensive", "eco-efficient" and "sustainable" strategies.

Whilst for many construction businesses these strategies may well appear to be impracticable and too far from their current trading reality there is evidence from the UK construction industry that practices such as Partnering and Value Management are providing a platform for the development of eco-efficient and sustainability strategies. Mutual objectives; continuous improvement; and problem resolution are the three essential components of partnering [9] which provides a framework to bring about the collaboration, value sharing and long term risk and benefit sharing necessary to achieve sustainable developments.

7.0 Acknowledgements

This paper has been compiled from work carried out on a range of UK national and international projects including: CIB Working Commission W82; UK Government, Office of Science and Technology (OST) and Department of Environment, Transport and the Regions (DETR)work on sustainable indicators for construction; DETR funded Construction Productivity Network and Construction Industry Environmental Forum; Chartered Institute of Building (CIOB), environment committee work in the UK.

8.0 References

1. Latham, Sir M. (1994) Constructing the Team, HMSO.
2. The Presidents's Council on sustainable development (1996) Sustainable America: A new consensus, US Government.
3. DOE (1996) Indicators of Sustainable Development for the UK, HMSO.
4. Dodds, F. (1997) The Way Forward - Beyond Agenda 2 1, Earthscan, UK
5. Various (1997)The Greening of Industry for a sustainable future, The Advisory Council for Research on Nature and the Environment and the Greening of Industry Network.
6. BREEAM, BRE Environmental Assessment Method, CRC Publications
7. Welford, R. Jones, D. (1994) Measures of sustainability in business, ESRC Global environmental change programme.
8. Pezzey, J (1989) Definitions of Sustainability, UK CEED No 9.
9. Construction Industry Board (1997) Partnering the Team, Thomas Telford.

The Need for the Implementation of Quality Management Systems in South African Construction

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Abstract

People are not similar in terms of personality traits, personal goals, philosophy and culture and consequently require a system, or systems to enable them to be consistent and achieve goals first time every time.

Consistency only results from a documented Quality Management System (QMS) which effectively integrates Quality Assurance (QA), Quality Control (QC) and Quality Improvement (QI).

QMS's also facilitate the synergy between occupational health and safety, productivity and quality, as they ensure the use of, inter alia, documented procedures and instructions which when followed prevent defects, accidents, rework, waste, and ultimately complement the sustainability of the environment.

Clients and users seek assurance: that the construction process will not result in fatalities, injuries and disease, damage to the environment, and that buildings and structures will be free from defects, costly maintenance and will not compromise the environment or adversely affect the inhabitants.

To this end, findings of descriptive surveys conducted in South Africa among general contractors will be presented which include inter alia: most contractors do not have a documented QMS; competitive advantage, improved productivity and reduced cost predominated among reasons for implementing a documented QMS; cost, client satisfaction, productivity and future work predominated among factors negatively affected by non-achievement of quality, and unqualified artisans, shortened project periods, inadequate details and inadequate specifications predominated among factors which negatively affect quality.

Keywords: Quality Management Systems, synergy, sustainability, environment, client satisfaction

1 Introduction

Quality means conformance to requirements, nothing more, nothing less [1]. Construction of various structures, as general activities, needs to conform to requirements [2]. When we know the requirements there is no opportunity for varying interpretations of what is required. The requirements are contained in, inter alia, contract clauses, specifications, standards, schedules, drawings and details. If there is a possibility of relativity then the requirements should be mutually agreed and confirmed [3]. The degree to which these requirements are met will determine the level of customer satisfaction upon or after completion of a construction project and hence contribution to the sustainability of the built and general environment [4].

However, as with most products or services, customers want to be assured prior to commencement and after completion of a project or service that they will be provided with a 'quality' product or service [4]. According to Landin [5] the demand for quality assurance in construction is increasing.

Assurance does not mean guarantee, it means confidence. Confidence in turn results from consistency. As people are not similar in terms of personality traits, personal goals, philosophy and culture, they require a system, or systems to enable them to be consistent and achieve goals first time every time. Consistency will only result from a documented quality management system (QMS) which effectively integrates quality assurance (QA), quality control (QC) and quality improvement (QI) [3].

2 Quality as a holistic requirement

Occupational fatalities, injuries and disease and damage to the environment constitute defects as they are not project requirements. Completing an activity or project without incurring any of the aforementioned defects constitutes successful completion [6].

2 The cost of non-conformance (CONC)

According to Crosby [1], the CONC is all the expense involved in doing things wrong, inter alia, rework.

Research conducted in the United States of America by the Associated General Contractors (AGC) [7] of nine industrial projects determined the average cost of rework to be 12,4% and normal work to be 87,6% of project costs. The distribution of the 12,4% is scheduled in Table 1.

Distribution of rework	Response (%)
Owner changes	3,3
Design errors	3,3
Construction Errors	2,8
Other	3,0
Total	12,4

Table 1: Distribution of rework on nine American industrial projects [7].

Research conducted among South African general contractors determined the average cost of rework to be 13% of project value.

Based on the 32 203 million (at current prices) of construction completed in South Africa in 1996 and an average of 13%, the cost of rework could have been R4 186,4 million [8].

3 Need for QMS's

Kerzner [9] cites oral communication, which is preferred by most people in the construction industry, as a major source of communication breakdown. Oosthuizen [10] maintains that this problem can be circumvented by finalising the process of communication and recommends the use of checklists and the implementation of a QMS.

Problems related to health and safety, productivity and quality can frequently be traced to substandard, inconsistently applied or non-existent operating procedures and practices [11]. Standard operating practices and procedures are the core component of quality management and health and safety management systems as they guarantee uniformity of operation throughout an organisation. They effectively ensure that each time a task is performed it is done consistently, correctly and safely [11].

The implementation of a QMS on a project will ensure that construction conforms to specified requirements in all respects as it identifies the procedures, checklists, resources, activities and responsibilities [8].

QMS's also facilitate the synergy between occupational health and safety, productivity, quality and the environment as the use of, inter alia, documented procedures and instructions prevent defects, accidents, rework, waste and damage to the environment [4].

5 Cost and benefits of a QMS

The implementation of a quality management system based on IS0 9000 should realise the following benefits: common language for communicating QA; increase in client confidence; avoidance of client assessment; increased competition for 'quality' products and services; increased client satisfaction; reduced quality and corrective costs; increased client base, and competitive edge for certified contractors [12].

Mahoney [13] says a paper presented at the Public Works Department of New South Wales' seminar: 'Quality Assurance in Public Works Projects' noted overseas reports of a 5% saving in construction costs from a 1% expenditure to implement a quality system. A study by the Public Works Department of seven Australian projects ranging in value from A$8m to A$250m indicated direct failure costs in excess of 10% of construction value and proactive expenditure between 1 and 2% of construction cost on 'prevention' i.e. a quality system, together with another 1% for 'appraisal' can keep the direct failure costs below 2% of construction value.

6 Designers

A study carried out by the Building Research Establishment (BRE) in the United Kingdom on building defects concluded that 50% of the defects were attributable to design. A further examination of these 'design' defects (more than 1000 defects identified in the study) revealed that most of them were the result of either poor technical detailing or the oversight of specific requirements. Faults defected at the site require investigations, additional drawings and rectification. The process consumes valuable time at the expense of other work, and because of this, the total cost of the defect, investigation and rectification can be up to 5 times higher than if the fault is detected at the drawing board. The objective of design control is to have a thorough understanding of the requirements and thereby reduce the number of faults by detecting them at the drawing board [14].

Although there is an increasing move towards design-and-build and also the use of construction management in some countries, by and large, the traditional mode of procurement remains. It is therefore essential for both designers and contractors to practise IS0 9000. This will facilitate better understanding of the customer-supplier concept, which will lead to a better quality end product [14].

7 Construction waste

According to Bossink & Brouwers [15] 13 to 30% of all solid waste deposited in landfills in various countries consists of construction and demolition (C&D) waste. Figures from Germany and Western Europe indicate the ratio between the weight of C&D waste to be 1:2. Based on a yearly amount of 12 800 000 ton C&D waste and this ratio, the absolute yearly amount of construction waste in the Netherlands will be approximately 4 224 000 ton [15]. Data from Brazilian and Dutch construction sites indicate that construction waste ratios on site are as high as 20-30% and 9% of the weight of total purchased materials respectively [15].

According to Graham & Smithers [16] potential construction waste is caused by inefficiencies in design, procurement, materials handling, operation or residual on-site waste such as packaging. Research also indicates that clients can be a source of waste through careless inspection procedures, variation orders, or during part possession.

Waste minimisation strategies include inter alia, design focus and waste management [16]. Design focus includes: modular design, and adequate documentation and detailing to minimise construction waste as a result of construction errors attributable to design and variation orders. Waste management activities such as: project analysis; increased control of subcontractor procurement and supervision; improved documentation, and quality control contribute to the minimisation of waste.

QMS's can clearly complement design and waste management activities directed towards reducing construction waste and by doing so, complement the sustainability of the environment.

8 Integration of systems

The ConQuest Research Group [17] advocates the inclusion of environmental, and health and safety issues as quality criteria. According to Renfrew[17] the introduction of QUENSH, a single system covering environmental, health and safety and quality aspects will be more efficient than separate systems. The reasons cited include: a single activity plan; consolidated paper work, and a single project file.

9 Research

153 general contractors who were either members of the Building Industries Federation of South Africa (BIFSA) or the South African Federation of Civil Engineering Contractors (SAFCEC) responded to a national postal survey. This consitituted a 12,9% response rate.

Table 2 indicates the majority of contractors seem to support Cornick's [18] argument regarding the problem of defining quality. 'Conformance to requirements' and 'Excellence' were selected more frequently than other defmitions of quality. Excellence is one of those definitions which are not easy to manage and hence ensure, it is relative, and consequently it leaves much for interpretation.

Definition	Response (%)
Best practice	9,2
Conformance to customer requirements	18,3
Conformance to requirements	26,8
Customer satisfaction	13,4
Durability	4,1
Excellence	26,1
Other	2,1
Total	100,0

Table 2: Contractor selected definitions of quality

88,2% of contractors had a quality policy, not necessarily written. A quality policy embraces the overall quality intentions and directions of a project as regards quality. A policy, especially written also indicates commitment.

60,5% of respondents did not have a documented Quality Management System (QMS). This situation suggests that there is lack of coherence and fundamental thinking in quality management to the majority of respondents. A documented QMS is fundamental to the effective operations of a quality management system. It provides the framework for quality assurance and the basis for quality improvement. It is through a documented QMS that the contractor will be able to deal with the main areas of concern in a quality management system, which are: control and maintenance of the quality system; control functions to eradicate quality deficiencies; feedback to ensure effective operation of both controls is being achieved, and a review of the declared quality system to ensure that it reflects policy.

Of the 60 contractors who had a documented QMS, one contractor had IS0 9002 certification. Various specialist entities of four contracting groups (representing 3.3%

of respondents) had IS0 9000 series certification, their activities including inter alia, piling, pre-cast concrete work, steelfixing, electrical and process engineering.

Standard work procedures, verbal or written, followed by pre-activity discussions predominated among actions to achieve quality (Table 3). The percentage response indicates that no particular action was used by the majority of contractors.

Agency	Response (%)
Pre-activity discussions	43,8
Standard work procedures	49,0
Visual checks	10,3
Tests	28,8
Samples / References	15,0
Designer interactions	7,2

Table 3: Actions to achieve quality

Those contractors who had a QMS cited 'Competitive advantage' most frequently as the reason for implementing a QMS. Rightly, other respondents cited the reasons behind implementation of a documented QMS as 'Improve productivity', and 'Reduce cost' (Table 4).

Reason	Response (%)
Improve productivity	17,6
Quality problems	7,2
Reduce cost	14,4
Client pressure	7,8
Competitive advantage	24,8
Other	3,3

Table 4: Reasons for implementing a documented QMS

Table 5 indicates the frequency at which project parameters and other aspects are negatively affected by the non-achievement of quality. 'Cost', 'Client satisfaction', 'Productivity' and 'Future work' were identified most frequently. Non-achievement of quality has far reaching consequences for clients, designers, contractors, and immediate users of a constructed facility or occupants.

Project parameter/Aspect	Response (%)
cost	75,8
Productivity	62,7
Schedule	41,8
Client satisfaction	71,2
Environment	13,1
Rapport with designers	33,3
Future work	62,7

Table 5 : Project parameters/aspects negatively affected by non-achievement of quality

Table 6 schedules the factors negatively affecting quality. 'Shortened project periods', 'Unqualified artisans', 'Inadequate details' and 'Inadequate specifications' predominated.

Factors	Response (%)
Competitive tendering	37,3
Shortened project periods	66,0
Lack of quality pre-qualification	22,2
Lack of contractor registration	16,3
Adversarial relationships	22,2
Inadequate specifications	51,0
Inadequate details	53,6
Design	20,3
Unqualified artisans	67.3
Increased subcontracting.	20.9
Variations	19,0
Inadequate health and safety	20,3
Inclement weather	14.4
Cvclical industrv	26.1

Table 6: Factors negatively affecting quality

According to Rwelamila [19], project procurement systems provide quality management frameworks. Therefore it is important to address the question of suitability of procurement system when addressing quality management issues. Contractors were asked to rate the basic procurement systems listed in Table 7 according to their suitability for achieving quality. Although generally between 30 and 40% of contractors stated that all procurement systems were suitable in addressing quality problems 62,4% of contractors stated that 'Design and build' procurement system is considered to be `Suitable'/`Very suitable'. 'Package deal and turnkey contracts' systems were cited as `Suitable'/`Very suitable' procurement systems for achieving quality by 58,6% of the respondents.

Procurement system	Response (%)						
	Very unsuitable	Unsuitable	Neutral	Suitable	Very suitable	Don't know	Total
Construction management for a fee	5,1	13,9	23,4	35,0	12,4	10,2	100,0
Design and build	5,8	65,	21,0	42,8	19,6	4,3	100,0
Management contracting	37,	82,	29,2	34,3	14,2	10,4	100,0
Package deal & turnkey contracts	5,0	57,	25,7	35,0	23,6	5,0	100,0
Project management	2,2	95,	21,2	40,1	21,2	5,8	100,0
Traditional	5,2	7,4	23,7	40,7	17,1	5,9	100,0

Table 7: Suitability of procurement systems for achieving quality

Education influences commitment to 'do it right first time'. Current thinking in practising total quality management (TQM) [20] demands the involvement of all stakeholders in a quality management system, hence education is needed across all levels of people involved in a project. Table 8 provides an indication of the extent of education in quality. The percentage of employees who had received education in quality increased commensurately with their organisational responsibility. These quality increased commensurately with their organisational responsibility. These results do not support the requirements of TQM, because a significant number of employees do not receive education in quality.

Occupation	Percentage educated in quality (%)						
	0%	>0 ≤25%	>25 ≤50%	>50 ≤75%	>75 ≤99%	100%	Total
Top management	27,0	3,9	7,9	5,9	5,9	49,4	100,0
Middle management	29,8	6,4	15,6	11,3	12,1	24,8	100,0
Site agents/managers	34,5	6,5	13,7	8,6	15,8	20,9	100,0
Foremen	34,2	8,2	14,4	7,5	15,8	19,9	100,0
Junior foremen	41,5	9,6	14,1	10,4	11,9	12,5	100,0
Artisans	40,1	15,6	17,0	11,6	8,8	6,8	100,0
General workers	99,3	0,0	0,0	0,7	0,0	0,0	100,0

Table 8: Extent of education in quality

'Training", "Education', 'Focus' and 'Publicity' predominated among quality related aspects requiring attention (Table 9).

Aspect	Percentage educated in quality (%)				
	More	Adequate	Less	Don't know	Total
Client intervention	14,0	49,3	34,0	2,7	100,0
Designer intervention	30,2	59,1	9,4	1,3	100,0
Education	88,1	9,9	0,7	1,3	100,0
Focus	73,6	21,3	0,7	4,4	100,0
Legislation	18,7	49,3	27,1	4,9	100,0
Publicity	57,2	38,6	1,4	2,8	100,0
Training	92,5	6,8	0,0	0,7	100,0

Table 9: Degree of attention required

10 Conclusions

Clients need assurance that requirements will be conformed to.

The non-achievement of quality has a substantial negative effect on: cost, health and safety, productivity, schedule, the environment, client satisfaction and the ability to obtain future work. However, the effect of the non-achievement of quality on the environment is not appreciated by South African contractors.

There are factors within and outside the control of contractors which affect quality; the South African contractors identified: shortened project periods; inadequate specifications and details, and unqualified artisans most frequently. Procurement systems also influence the achievement of quality, the Design-Build form being identified most frequently.

QMS's complement conformance to requirements as they identify the procedures, checklists, resources, activities and responsibilities. Generally, South African contractors have not implemented QMS's and rely on informal actions to achieve quality.

Education and training in quality is essential to empower management and workers to contribute to quality management. However, South African contractors have generally not undertaken education and training in quality and in fact identify both as the aspects relative to quality requirement the most attention.

Although South African contractors realise the importance of quality they have not implemented appropriate practices and systems, and ultimately QMS's, to assure conformance to requirements and sustainability of the built and general environment.

The need for the implementation of QMS's in South African construction is amplified by the CONC.

11 Recommendations

Contractors should calculate the CONC for all their projects in an endeavour to raise the level of awareness of the impact of non-conformance to requirements.

Clients should deliberate the suitability of procurement systems in general, but certainly relative to their suitability in terms of enhancing the achievement of quality.

Contractors should implement or plan to implement QMS's as a requirement for pre-qualification on projects in excess of a certain value.

Contractors should educate and train all levels of management and workers in quality to facilitate conformance to requirements and the implementation of QMS's.

12 Acknowledgements

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References

1. Crosby, P.B. (1984) *Quality without tears. The art of hassle free management,* McGraw-Hill Book Company, New York.
2. Rwelamila, P.D. (1994) Hybrid value engineering: the challenge of construction project management *in* the 1990s, *International Journal of Project Management,* Vol. 12, No.3. pp.157-164.
3. Smallwood,. J. J. (1997) Constructing reinforced concrete frames without injury and fatality : The relationship between health and safety and quality. *The Civil Engineering and Building Contractor,* March. pp.40-43.
4. Rwelamila, P.D. and Smallwood, J. J. (1996) The need for the implementation of quality management systems in South African construction. *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernizaton and Education,* Beijing, October 1996, CD-file:///D1/papers/060-069/061/p06 1 .htm.
5. Landin, A. (1995) Specialist contractors' approach to quality management in Sweden. *Building Research and Information,* Vol. 23. No. 2. pp. 110-l 13.
6. Smallwood, J.J. (1996) The role of project managers in occupational health and safety. *Proceedings of the 1st International Conference of CIB W99 – Implementation of Safety and Health on Construction Sites,* Lisbon, September 1996, pp.203-213.

7. The Associated General Contractors of America (AGC). (1992) *An Introduction to Total Quality Management,* AGC, Washington, D.C.
8. Smallwood, J.J. (1997) Total Quality Management in Construction. *ProjectPro,* November. pp. 17- 19.
9. Kerzner, H. (1984) *Project Management.* 2nd Edition, Van Nostrand, Reinhold Company Inc., New York.
10. Oosthuizen, P. (1994) *The silent revolution -project management – how to make business work,* PM Publishers cc, Arcadia.
11. Hood, S. (1994) Developing operating procedures: *9* Steps to Success. *Accident Prevention,* May/June. pp. 18-21.
12. Pheng, L.S. & Omar, H.F. (1997) Integration, segmentalism and the maintenance of quality management systems in the construction industry. *Building Research and Information,* Vol. 25. No. 1. pp. 36-49.
13. Mahoney, L. (1992) Quality assurance. *The Chartered Builder,* June. pp. 35-39.
14. Lam, S.W., Low, C.M. & Teng, W.A. (1994) *IS0 9000 in Construction,* McGraw-Hill Book Company, Singapore.
15. Bossink, B.A.G., Brouwers, H.J.H. & van Kessel, R.A. (1996) Financial consequences of construction waste. *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernization and Education,* Beijing, October 1996, CD-file:///D1/papers/120-129/122/p122.htm
16 Graham, P. & Smithers, G. (1996) Construction waste minimisation for Australian residential development. *Asia Pacific Building and Construction Management Journal,* Vol. 2. No. 1. pp 14-19.
17. Barrett, P.S. & Curado, M.T. (1996) Quality and environmental management: How should the construction industry face new panaceas? *Proceedings of the 1996 CIB W89 Beijing International Conference – Construction Modernization and Education,* Beijing, October 1996, CD–file:///D1/papers/050-059/050/p 050.htm
18. Cornick, T. (1991) *Quality Management for Building Design,* Butterworth Architecture, London.
19. Rwelamila, P.D. (1994) Quality management in the SADC construction industries, *International Journal of Quality and Reliability Management,* Vol. 12. No. 8. pp 23-31.
20. Flood, R.L. (1993) *Beyond TQM,* John Wiley and Sons, England.

Management of Construction & Demolition Waste Streams

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Abstract
Utilisation of construction & demolition waste (C&D waste) by recycling can provide opportunities for saving energy, time, resources, and money. Furthermore, recycling and controlled management of C&D waste streams will save use of land and create better opportunities for handling other kinds of waste.

Recycling of C&D waste has been carried out since the start of human building activities. However, systematic recycling in the frame of professional building and construction industry is rather new. The prospect of the use of C&D waste depend on a range of factors related to the building and construction industry, and consumption of energy and resources, where the main three factors are population density, occurrence of and access to natural materials, and level of industrialisation.

To optimise the use of natural resources and C&D waste, to fulfil the requirements for materials for construction, and an appropriate operation of recycling plants there is a need for long term action plans concerning use of materials and co-ordination between different interests among authorities and companies within the building and construction industry.

The major constituents of an economic model for management of C&D waste streams, on which the author is working, is presented in this paper. The purpose of the model is to facilitate decision makers to achieve the goals of economic efficiency and environmental protection simultaneously with the aim of creating a stable market for recycled materials. An analyse of prospects of successful recycling of C&D waste in various parts of the World is presented, and aspects of implementation of waste management plans are discussed.

Keywords: Construction, Cost-Benefit, Demolition, Management, Recycling, Waste

1 The need for C&D waste management

In me European Union with a population of approximately 350 million, it is estimated that the annual generation of C&D waste is between 175 and 370 million tons or equal to ½ - 1 ton per capita per year [1]. This makes between 25 % to 50% of all municipal waste. The figure is probably representative for most of the industrialised world. A global C&D waste production of 2-3 billion tons per year may be a best wild guess.

In many countries, industrial as well as developing, C&D waste is considered as harmless, inert waste which does not give rise to problems. However, C&D waste consists of huge masses of materials which are often deposited without any consideration, often inviting illegal deposit of other kinds of waste. Moreover mixed C&D waste also often contains hazardous substances that percolate into the ground, due to paint and other surface treatment substances. Utilisation of the waste by recycling can provide opportunities for saving energy, time, resources, and money. Furthermore, recycling and controlled management of C&D waste streams will save use of land and create better opportunities for handling other kinds of waste.

Another great challenge is to reduce the impact of disasters, natural-, technical- or human made disasters, especially wars. It is evident that there is a great need for C&D waste management after such events.

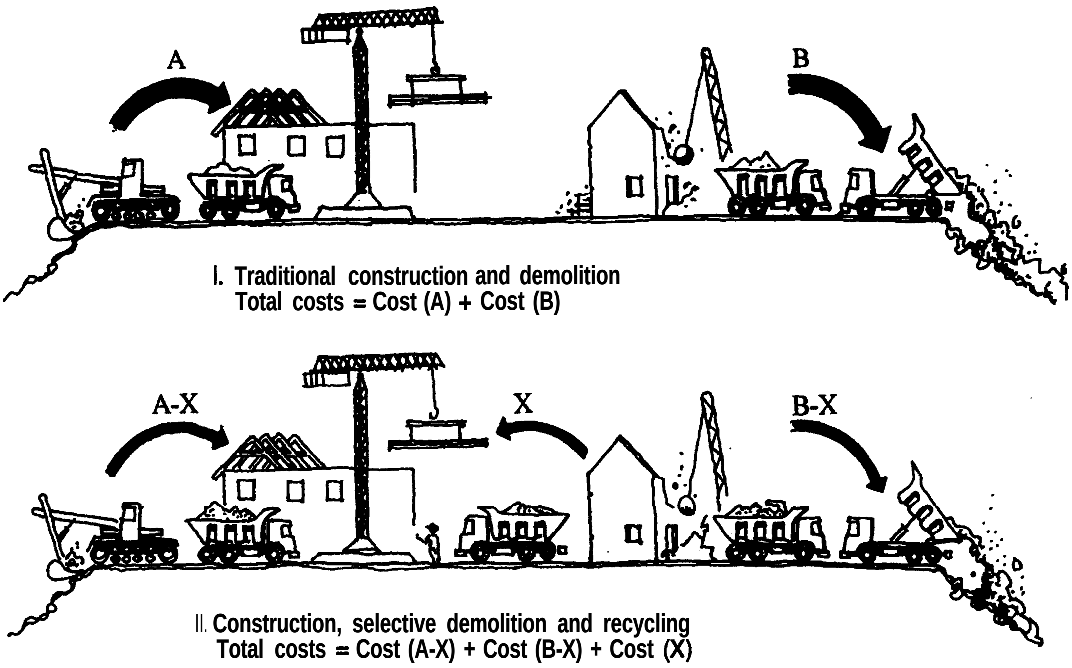

Figure 1:
Model of total costs of traditional and selective demolition. The top figure shows traditional construction and demolition where all natural resources are new and all demolition wastes are tipped. The figure below shows construction, selective demolition and recycling, where a part of the natural resources is substituted by recycled materials. This option often saves costs of transport, supply of natural materials and disposal of demolition waste.

2 Model for management of C&D waste streams

The decision of how to treat C&D waste normally has both political and financial aspects, with long or short time durability. Problems to take into consideration can be; whether a specific waste product should be sorted and recycled, where a permanent recycling plant for a specific region should be established, and at what capacity, or if materials shall be processed on-site or off-site for a specific project. Other problems can be to analyse the effects of different regulations and fees.

An economic model for management of C&D waste streams can facilitate decision makers to achieve economic efficiency and environmental protection simultaneously. This decision is often referred to as «Best Available Technique Not Entailing Excessive Costs» (BATNEEC). Such a model can be achieved by optimising the total costs and benefits of a C&D waste management system affected by the following items:

- Optimising the use of natural resources (by substitution with recycled products)
- Minimising energy- and water consumption (processing, dust suppression etc.)
- Minimising production of residual products (load on landfill, pollution)
- Minimising the transport load
- Minimising the risks in working environment (cost to keep a certain level)
- Minimising impact from dust-, vibrations-, CO_2-, noise emissions
- Minimising capital costs (investments in recycling plants etc.)
- Minimising of operational expenditures (salaries and maintenance etc.)
- Maximising the value of recycled products (material, energy)

Table 1: Items affecting C&D waste management

Input in the model should preferably be a monetary value for as many of the items as possible. Public preferences are often expressed by taxes (landfill, transport, water and energy). Moreover monetary values should be placed on pollution, as well as dust-, vibration- and noise emissions. The impact from these items will vary widely from place to place, and definition of monetary values will require considerable efforts. Many items can alternatively be represented by a non monetary value (level of impact), when different alternatives are evaluated, by using the model mainly to structure a problem.

During optimisation, it is important to consider all levels involved in the process, from the micro economy at the building site, to the global economy, in order to obtain a fair distribution of responsibilities and costs. When the economical inputs have been stipulated the cost-benefit should be analysed at the following levels:

C - for a contractor (e.g. demolition, transport, disposal, value of material)
L - for a local level (e.g. pollution, road maintenance, costs for landfills)
R - for a region (e.g. pollution, use of resources and land)
N - nationally (e.g. road maintenance, fees or subsidies)
G - globally (e.g. CO_2-emissions, use of resources)

Whether or not the goal at a certain level is maximum profit, or cost minimisation, a general economical goal to minimise the total cost (T) can be presented as follows:

T-cost = C-cost + L-cost +R-cost +N-cost + G-cost, T-cost $\rightarrow 0_{min}$

Optimisation of the items mentioned in Table 1 are often in conflict. As an example it can be mentioned that the best solution in a transport perspective may be to have many small recycling plants at different sites, though the most feasible alternative for an operator would be to have one big centrally located plant. These issues are of extra importance concerning the marginal waste. fractions such as plastic, plate glass, gypsum etc. Many producers of building products are gradually accepting the idea of taking back waste from their own products for reprocessing, but this often requires transit stations for a sound transport economy.

In order to establish goals for a recycling effort in a region, it is desirable to assess, the existing situation. Qualitative and quantitative evaluations must be made of the productions and streams of C&D wastes in all phases of the life cycle of buildings and structures. Attempts must also be made to forecast the probable development within a foreseeable future exemplified with different scenarios. The quantities and streams of C&D waste are often difficult to determine. Large quantities of waste produced never appear in official waste treatment systems, and are therefore not registered.

The inventories should include assessment of existing treatment facilities for C&D waste and the existing market for products that are to be substituted. Studies should also be made of the possibilities to co-ordinate recycling of C&D waste with waste products from other industries, for instance power plants and domestic refuse incineration plants. The objective for many countries has so far been the recycling of a certain percentage of the total amount of C&D waste. Targets should preferably instead be set for the best qualitative use of materials.

There are often discussions about avoiding «downcycling» of materials and to produce «high quality>. products. «High quality>> reuse of C&D waste does not always correspond to production of the product with the highest value, but rather the most feasible product in a specific project or region. It is important to consider that resources are also used to produce recycled products. As an example it can be mentioned that crushing of concrete into concrete aggregates will use more energy, than if the material was used as a coarse filling material, and water used to reduce dust from crushing will create a residual product. Moreover the concrete made from concrete aggregates often require use of more cement.

An early prototype of the model has been used for C&D waste management in Denmark's capital Copenhagen incl. suburbs (1. mill. inh.). For treatment of the rubble fraction (concrete, masonry, asphalt), the optimal solution was found to be a recycling plant with a capacity of 500.000 tons pr. year, which now is established 4 km from the centre of town.

It is important that the model used to analyse the options for handling of C&D waste streams is presented in a form, that all parties involved in, and depending on, a decision, can easily understand. A detailed mathematical equation might not be useful if the decisions based on the result are difficult to implement.

3 Prospects of recycling in different places in the World

The three main factors affecting the prospects of recycling of C&D waste are; population size and density, occurrence of-, and access to natural raw materials, and level of industrialisation. In Table 2, the prospects of systematic recycling of C&D rubble in different parts of the World have been analysed according to these factors.

Area code	Population density	Natural raw materials and deposits	Level of industria-lisation	Example	Prospects of successful recycling
I	High	Adequate	High	Many cities in EU, USA and the Far East, e.g. Hong Kong, Copenhagen, (Denmark)	+ + +
II	High	Adequate	Low	Many megacities in the Third World: Mexico City, (Mexico) Jakarta, (Indonesia)	+ + +
III	High	Scarce	High	Amsterdam, (The Netherlands)	+ + + +
IV	High	Scarce	Low	Dacca, (Bangladesh) Shanghai, (China)	+ + + +
V	LOW	Adequate	High	Rural Scandinavia	++
VI	LOW	Adequate	LOW	Rain forests and mountain regions in developing countries	+
VII	Low	Scarce	High	Kuwait, Abadan, (Iran)	+++
VIII	Low	Scarce	Low	Steppelands, Sandy deserts or tundra's in developing countries	+

Table 2:
Table summarising the main factors affecting the prospects for successful recycling of C&D waste. Rating from "+" (doubtful) to "+ + + +" (profitable)

From Table 2 three examples are highlighted below:

Amsterdam, in the Netherlands, is the first example. The city is densely populated. Natural raw materials are scarce and the level of industrialisation is high. It is not surprising that the highest possible value recycling of C&D waste is practised in the Netherlands. The idea of deliberately mixing wastes which can be separated does not appeal to the Dutch.

Copenhagen, in Denmark, is the second example. The city is densely populated and the level of industrialisation is high. However, because there is ample supply of natural raw materials, economy and common sense dictate lower value recycling than in Amsterdam. Production of pure fractions of C&D rubble has proved uneconomical and the commercial market has shown preference for blended rubble. This is so in spite of the fact that public authorities for environmental reasons have discouraged the use of mixed materials.

Dacca, in Bangladesh, is the third example. The city is densely populated. Access to natural raw materials is difficult, and like other Third World cities Dacca struggles with the problem of reducing huge quantities of municipal solid waste that daily adds to already immense and unsanitary landfills. It would appear that the use of C&D rubble as road construction materials could substantially assist in solving both a waste disposal problem and a raw materials supply problem. This is true also for other large cities in the Third World which, contrary to Dacca, are located close to abundant raw materials deposits, but where permanently congested traffic conditions make access to the deposits difficult. Mexico City is an example in point.

4 Implementation

In order to reach the goals of C&D waste management, it is necessary that all barriers and obstacles are detected and considered. A long-term action plan has to be made, combined with adequate development and research. Implementation of the necessary economical-, technical- and administrative instruments require that initiatives, involving legislation's and regulations, are taken.

4.1 Economy

In a market economy, the choice between recycled and natural materials depends upon price and quality. The quality of concrete with recycled aggregates can be the same as that of concrete with natural aggregates, but recycled concrete aggregates are regarded with suspicion.

Hence, recycled concrete materials will be preferred only when the price of such aggregates is considerably lower than that of the natural materials, even when the recycled aggregates meet given specifications. The economic barriers can be overcome by introducing economic instruments which encourage recycling and use of recycled materials. As an example, taxes demonstrating the true cost to society for waste accumulation, and fees in favour of recycling should be mentioned.

4.2 Policies & Strategies

C&D waste must be considered as a specific individual type of waste associated with the building and construction industry. It is important that the management and handling of waste is carried out by the industry itself. Generally, the building and construction industry is relatively conservative, and changes in normal procedures often take time and need long-term policies and strategies.

One of the most important barriers is the many different interests in C&D waste. It is usually the politicians, departments and public offices concerned with environmental issues who prepare the policies concerning waste recycling and reduction, whereas the building and construction industry is controlled by politicians, departments and offices concerned with housing, construction and public works. To co-ordinate the interests of all parties, especially concerning implementation of cleaner technologies in the industry, it is necessary that long-term policies and strategies, with respect to achieving goals for recycling of C&D waste should be adopted. These goals should then be continuously revised in accordance with the political and environmental situation, and followed up by adequate legislation and regulation at all levels, national, regional and local.

4.3 Certification of recycled materials

Even when recycled materials fulfil current standards for natural material, and the prices are competitive with prices of natural materials, certain obstacles still exist. Due to traditions and psychological barriers, the general attitude towards recycling in the building and construction industry is largely inhibitive to the utilisation of recycled materials Therefore; it is of great importance that recycled materials are officially certified so they can be accepted by all parts in the building and construction industry.

It is recommended that considerable emphasis is placed on specifying the areas of utilisation and quality standards for recycled materials. These must be in accordance with the local demand in order to improve confidence in the recycled materials and solve problems regarding the responsibility of using recycled materials.

4.4 Planning demolition projects

Demolition has until recently been regarded as a low technological process. Rapid demolition and disposal of structures were the main aims of the contractor. Special measures to separate the different types of materials were not possible due to the time factor, nor were they desired.

A necessary condition for the recycling of building waste is carefully sorting of the waste. Waste materials from new constructions and rehabilitation, such as surplus, over ordered materials, packaging etc., are sorted at site or at a suitable treatment site according to the organisation of the work site. This separation into materials categories is rather simple. The sorting of waste from demolition is, however, a more complicated process.

Optimal handling and recycling of C&D waste depends on the materials being sorted in-situ and in co-ordination with the demolition process. It is therefore necessary to alter the traditional methods of demolition and introduce <<selective demolition>.. This requires that before and during the demolition process an effective sorting of the different material categories is carried out, thereby preventing any mix of materials leading to pollution of, for instance, recyclable concrete/masonry rubble with wood, paper, cardboard and plastics etc.

It is recommended that demolition projects should be planned and controlled in detail, in the same way as all other building and construction projects to ensure selective demolition and correct handling of the demolition waste.

4.5 Education and information

The improvement of cleaner technology and achievement of goals for reuse and waste minimisation is inextricably tied to an understanding of the different problems in integrated building waste management and recycling of building and construction waste materials. Therefore, education and information within all parts of industry on all levels are needed.

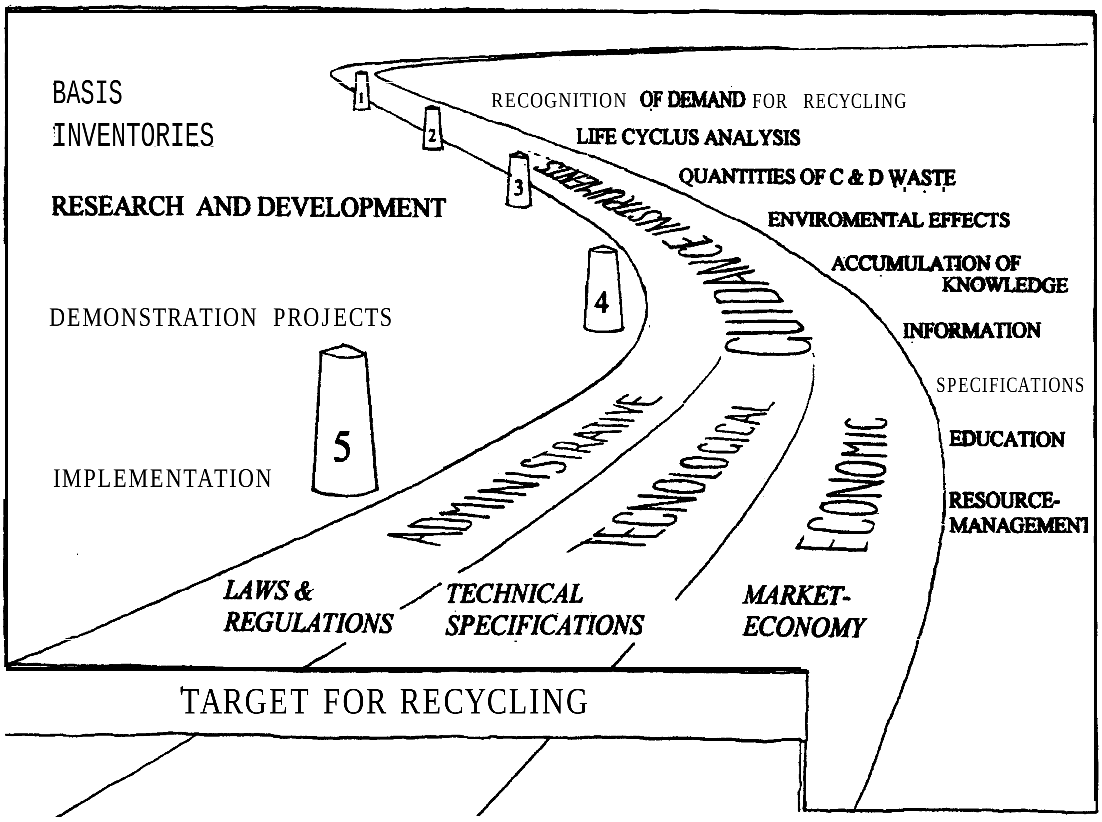

Figure 2:
The way to the target for C&D waste management relies on economical--, technical- and administrative guidance instruments jointly with a long-term commitment.

5 Conclusions

Recycling of C&D waste is more feasible in some places in the World than others. With a well defined analyse where all items affecting the choice of C&D waste treatment facilities are considered, it will be possible to find the optimal solution for each type of waste product in various situations. Many barriers have to be considered during the implementation of a C&D waste management plan, which requires long term action plans involving economical-, technical- and administrative guidance instruments jointly.

References

[1] Symonds Travers Morgan/ARGUS (1995) ***Construction and Demolition Waste Project in the framework of the Priority Waste Stream Programme of the European Commission.*** Report of the project group to the European Commission.

[2] Lauritzen, Erik ***K.*** (1993) ***Demolition and Reuse of Concrete and Masonry,*** Proceedings of Third International Symposium held by RILEM in Odense, Denmark, 24-27 October, E & FN Spon.

[3] Lauritzen, Erik K., Hansen Torben C., Torring Mats (1997) ***C&D Waste Management - A Global Challenge,*** Svedala Waste Processing & Recycling Conference, Malmö, Sweden.

[4] Lauritzen Erik K., Hansen Torben ***C.*** (1997) ***Recycling of C&D Waste Research and Development 1986-l 996,*** Danish Environmental Protection Agency.

Sustainable Development and the Future of Construction, a CIB W82 Project

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Abstract

This international CIB Project aimed at answering the following question *: "What will be the consequences of sustainable development on the construction industry by the year 2010 ?"*.

This future study was focused on investigating the relationship and clearly defining the links between the principles of sustainable development and the construction sector. The followed methodology allowed to present and to take account of the specificity and orientations of more than ten countries, and to display a clear vision of what the construction sector could be in fifteen/twenty years in the framework of a sustainable development and how this goal could be reached.

The study was made of two main steps: a first step was dedicated to national efforts in order to get results at national level; a second step was dedicated to an international synthesis and the validation and dissemination of the results.

The study precisely led to :

- the identification of the issues, constraints and currently followed policies in the field of sustainable construction;
- the identification of the foreseen changes and mutations in the sector through answers given by experts on five questions dealing with : i) the kind of buildings which will be build in 2010 and how existing buildings will be adapted, ii) the ways of designing and constructing, iii) the kind of materials, services and components, iv) the kind of skills and standards which will be required, v) the kind of cities and settlements which will be developed;
- the analyses of the consequences for the phases of the construction process;
- the definition of recommendations to the main driving actors of the sector;
- an illustration of best practices through some case studies, design methods, buildings or building products.

Keywords: building, environment, sustainable development, future studies.

1. Introduction

This international CIB Project was launched in the W82 Amsterdam meeting (Spring 1995). In accordance with the scope of this Commission dealing with "Future Studies in Construction" - to supply, analyze and interpret the external (exogenous) factors affecting the development and future of the construction field, and, to produce, formulate and evaluate its future alternative - the Project aimed at answering the following question:

" *What will be the consequences of sustainable development on the construction industry by the year 2010 ? "*.

"Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". According to this definition from the World Commission on Environment and Development (1987), it is clear that the various activities of the construction sector have to be regarded and analyzed when considering sustainable development. As a matter of fact, on one side, the build environment constitutes one of the main support (infrastructures, buildings,...) of the economic development, and, on the other side, its construction has significant impacts on resources (land, materials, energy, water, human/social capital) and on the living and working environment. Hence the construction industry has a lot of direct and indirect links with the various aspects of sustainable development. It is still an unsteadily concept, but it surely concerns the construction sector.

The First International Conference on Sustainable Construction held in Tampa in 1994 [1] introduced the following definition of sustainable construction "the creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles" (Kibert and alii).

This very broad definition must be seen only a starting point to build a more concrete definition of the concept of sustainable construction and to precise the stakes and issues of sustainable development with regards to the construction sector. More research is required to investigate the relationship between sustainable development and the future of construction (Figure 1).

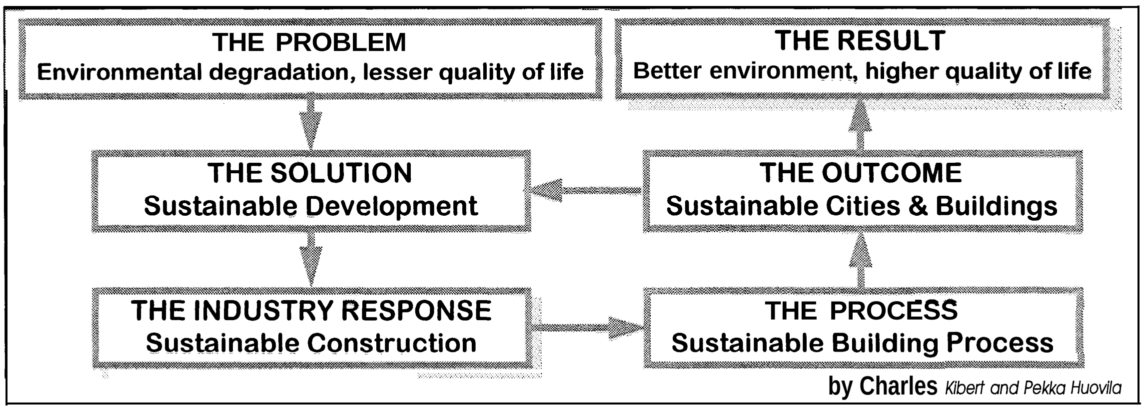

Figure 1: Sustainable Construction Road Map

2. Methodology

The study [2, 3] was focused on the clear definition of the links between the construction sector and the principles of sustainable development. It followed a methodology which had several main characteristics: i) it was an international study allowing to present and to take account of the specificity and orientations of various countries; ii) it was a future study aiming at defining a clear vision of what the construction sector could be in fifteen/twenty years in the framework of a sustainable development and how this goal could be reached; iii) it was carrying out by experts coming from organizations deeply involved in the topic at national levels.

The Project was divided in several tasks (Figure 2) grouped in four phases.

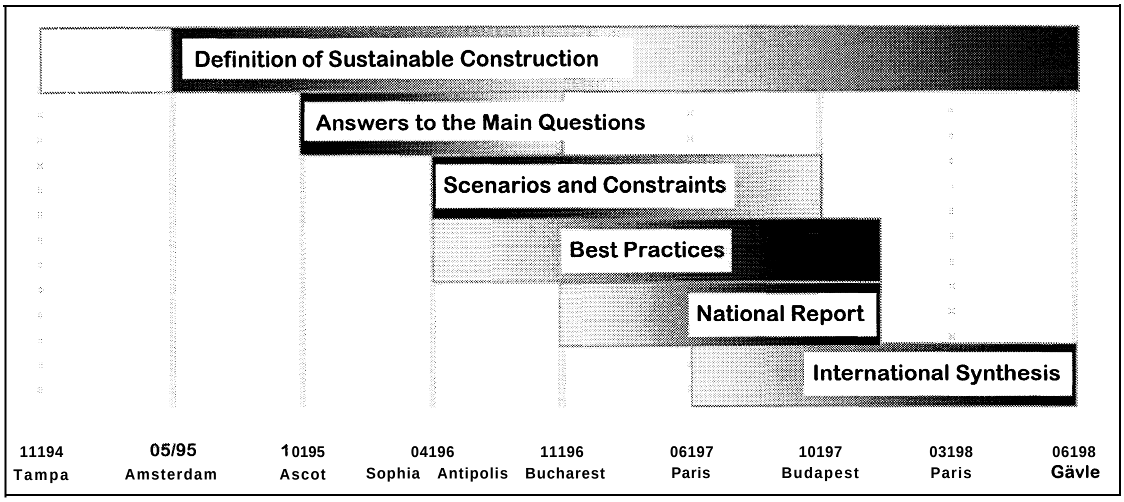

Figure 2: Main Tasks of the Project

Three different coordinators were nominated for the first three phases of the project: Sandy Halliday, for BSRIA, accepted to lead phase 1, Pekka Huovila, from VTT, led phase 2, and Caspar Richter, from sbr, led phase 3.

About fifteen countries were involved in some or all of these phases and eleven were able to produce a final National Report (Figure 3).

Countries	Organizations	Members
Belgium	CSTC	Frans Henderieckx
Finland	VTT	Pekka Huovila
France	CSTB	Luc Bourdeau
Hungary	ETE	Gyorgy Kunszt
Italy	Florence	P. Gallo & M. Sala
Japan	MIT	Tomonari Yashiro
Netherlands	TNO	Roël Lanting
Romania	Urbanproiect	Jana Suler
Spain	UPC/UZ	P. Alavedra & J. Dominguez
United Kingdom	BSRIA	Tom Smerdon
United States	GaTech	G. Augenbroe & Saeid Sadri

Figure 3: Main Members Involved in the Project

3. Phase 1: Definition of the concept of Sustainable Construction

Phase 1 of the Project sought to identify what each participating country or region understands by “Sustainable Development” and “Sustainable Construction”.

It is why it was asked to the 10/95 Meeting participants to present papers which gather national initiatives on Sustainable Construction and to try to discuss about a definition of sustainable construction [4, 5]. It was proposed to start from the definition provided by Kibert and alii.

The intention of the Meeting was to generate an interactive debate consistent with the holistic nature of the subject. In total thirteen papers from ten countries (Canada, Finland, France, Hungary, Netherlands, New Zealand, Palestine, Rumania, UK and USA) were received and discussed on a wide range of topics.

The meeting consisted of a series of informal interactive sessions to identify common themes and concerns. The papers were extremely diverse but common threads identified.

Several definitions of Sustainable Construction were offered which reflected the regional diversity and differing priorities in the participating countries. They included a more precise but still concise definition of "Sustainable Construction" derived from Kibert's one, to more general and detailed views such as the French one which introduces 24 criteria [6].

4. Phase 2: Answers to 5 main questions

The questions to be answered in Phase 2 were the following:

- *What kind of buildings will be build in 2010, and how will we adapt existing buildings?*
- *How will we design and construct them?*
- *What kind of materials, services and components will be used there?*
- *What kind of skills and standards will be required?*
- *What kind of cities and settlements will we have then?*

There was no common methodology given to participants on how to find answers to these questions. That was left open to be freely defined in each country: e.g. scenario for sustainable construction, analysis and documentation of expert interviews and brainstorming sessions. National studies consisting of answers to the five questions together with a more precise (i.e. more concrete) definition of sustainable construction from participating countries were asked to be presented in the 4/96 Meeting [7].

It was also decided that the precise content of the coming Phase 3 would be described in this meeting. The ideas of i) integrating the activities of other relevant CIB Working commissions and Task Groups and ii) including the presentation of some success stories were already risen.

Phase 2 was started with Belgium, Finland, France and the Netherlands. The number of participating countries increased soon to twelve after Australia, Canada, Hungary, Italy, Japan, Rumania, United Kingdom and United States decided to join the project.

It was not easy to agree on one common definition for Sustainable Construction. Therefore each country was given the liberty of using the Kibert definition or its own definition for Sustainable Construction to develop answers to the 5 main questions.

Answers differed between nations, and within nations. A complete map of answers from a country (Finland) is presented in Figure 4.

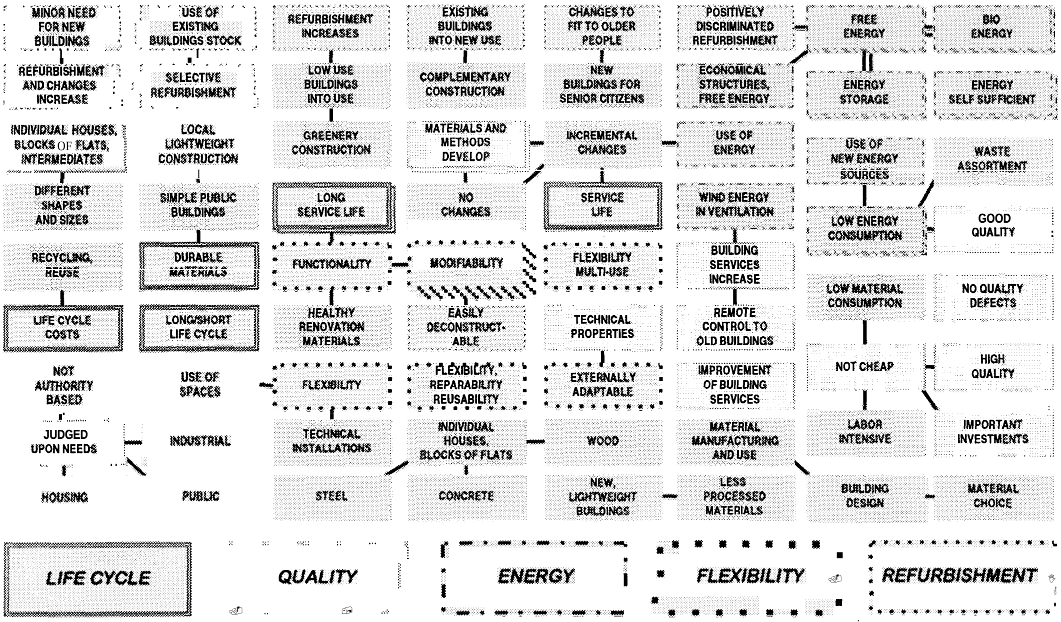

Figure 4: Main Themes of Sustainable Buildings in Finland in 2010

5. Phase 3: National Reports

First results of Phase 2 of the project rose a need for a common methodology to be applied in Phase 3 enabling later international synthesis based on national studies.

It is why a methodology to be followed was proposed in mid-96, which is based on a multi-dimension analysis of the problem (Figure 5). Three dimensions are introduced:

- Ecological principles (six principles are defined in the construction field in order to meet the three basic goals of a Sustainable Development: to eliminate resource depletion, to eliminate environmental degradation, and to create a healthy interior and exterior environment).
- Resources (four resources are concerned: land, energy, water and materials).
- Life-cycle phases of the construction process (five phases are defined: develop and plan, design, manufacture and construct, operate, deconstruct).

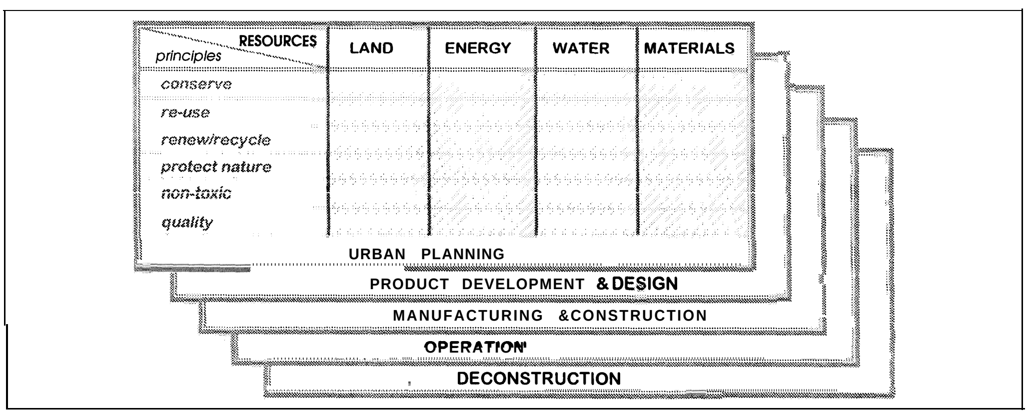

Figure 5: Proposed Format for National Reports

The idea was that for each point of this three-dimension space, it is possible to think about the consequences for the construction industry and therefore to give elements of answer to the five questions defined earlier.

A general important remark which came from several participating members was that the definition of Sustainable Development and therefore the definition of the ecological goals and principles which were proposed did not fit necessarily the concept in all the countries. As a matter of fact, it appeared from the Ascot and Sophia Antipolis papers that the concept from some countries can be much broader than the "ecological" concept proposed here [8, 9,10].

But on the other hand, this methodological approach offers an interesting support for thinking about consequences to the construction industry. It enables to grasp the overall idea and to debate over the appropriateness of activities meant to contribute to a Sustainable Development. It also provides a good instrument to make a synthesis of national reports.

It is why it was agreed to use this methodological approach for Phase 3 of the Project. To solve the problem linked to the general important remark mentioned above, it was agreed to give the possibility to every country to add to each dimension as many topics as needed.

At last it was also agreed that the project participants would present in their National Report best practices of Sustainable Construction from their countries.

6. Phase 4: International Synthesis

The last Phase of the Project was an international synthesis of the results (Figure **6).** That work, which started in Summer 97, was based on National Reports.

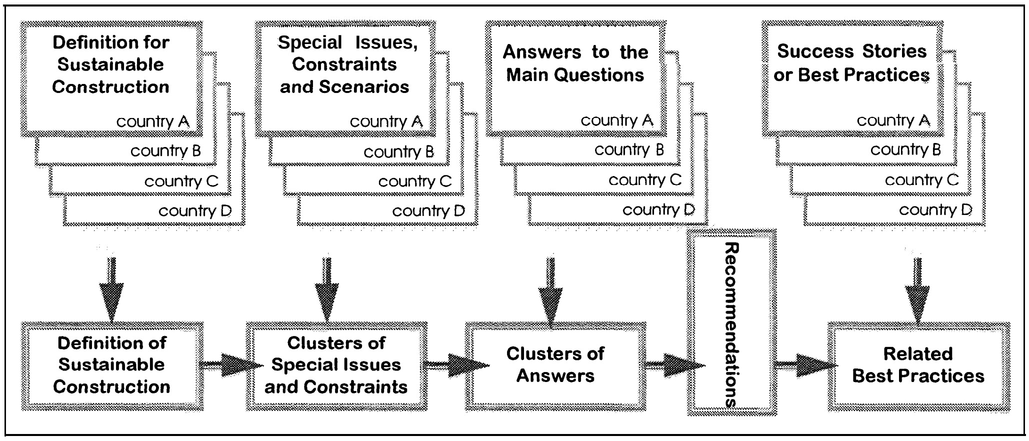

Figure 6: Methodology for the International Synthesis

The final results of the project give an international view of long term contribution by Sustainable Construction in Sustainable Development. Clusters of national differences, due to special issues and national constraints give more specific views on different levels and approaches by clusters of countries. Best practices of sustainable design are gathered. Recommendations for government, management of construction and machine industry and for research and development are also provided.

An example of synthesis of the answers given to the 5 main questions in the various national reports is reported on Figure 7.

Resources	Main issues	Consequences for cities and city planners
Land	Efficient use of land	Restricted suburbanisation
		Adaptation and regeneration of the existing built environment taking account of future needs
		Remediation of brownfield sites
		New soil cleaning technologies
		Land reclamation for industrial use
		More low density building
	Intensive use of land	High density building, underground building; double use of land
		Underground drilling techniques
		Building in nuisance zones
	Conservation of open space and green areas	Combined transport corridors (roads, rail, cables, ducts)
		Creating new space by underground construction
		No fragmentation, no ribbon building

Resources	Main issues	Consequences for buildings and designers
Land	Efficient use of land	Multi-functional buildings
		Temporary or transportable buildings
	Intensive use of land	Double use of land (above and underground)
		Flat roofs for recreational purposes
	Longevity of buildings	Design for flexibility/adaptability
		Support/infill modularity
		Design for life cycle performance
		Introduce standards for longevity in building codes
		High quality building
		Life cycle costing tools
		Understand needs and requirements of future users
	Greater use of existing buildings	Redestination of non-functioning buildings
		More refurbishment and retrofit activities
		Refurbishment techniques (vertical/horizontal extensions; lightweight constructions)
		Performance standards for regenerating existing building stock
		Better condition assessment methods
		Decision support tools demolition/ renewal

Figure 7: Example of Main Issues for the Resource "Land" and Consequences for City Planners and Designers

7. Conclusion

Sustainable construction should be an important component of creating a sustainable development. However, no clear consensus on the exact meaning of such a sentence seems to be agreed today. This W82 Project aimed at contributing to reaching such an agreed clear vision of the future of construction within a sustainable development assumption.

At the moment, the project led to a set of ten or so National Reports and an International Synthesis, most probably gathered in a CIB Publication, which contain:

- the identification of the issues, constraints and currently followed policies in the field of sustainable construction;

- the identification of the foreseen changes and mutations in the sector through answers given by experts on five main questions;
- the analyses of the consequences of sustainable development for the phases of the construction process;
- the definition of recommendations to the main driving actors of the sector;
- an illustration of best practices through some case studies, design methods, buildings or building products.

The main goal of the present international synthesis was to extract main issues from the national reports, to detect the common ones and to stress the main differences (in scenarios, consequences, recommendations to actors,...). The next step should be to reach a more consensus vision through a global common model (with of course eventually items specific to regions or countries) and to set up indicators and policies to translate this vision into reality.

8. Acknowledgments

The authors of this paper would like to thank, on one side, all the authors of the national reports and, on another side, Sandy Halliday and Cas Richter who coordinated Phase 1 and Phase 3 of the Project respectively.

9. References

1. Kibert, C. (1111994) *Proceedings of the First International Conference on Sustainable Construction,* Tampa.
2. Bourdeau, L., Halliday, S., Huovila, P., Richter, C. (9-12/6/1997) Sustainable development and the future of construction. *2nd International Conference on Buildings and the Environment.* CSTB-CIB, Paris.
3. Huovila, P., Richter, C. (19-21/8/1997) Life cycle building design in 2010. *International Conference on Engineering Design,* ICED, Tampere.
4. BSRIA (1111995) *Report on the CIB W82 Commission Ascot Meeting.* BSRIA 79 150, Bracknell.
5. CSTB (3/1996) *Appendix to CIB W82 Commission Ascot Meeting: contributions.* CSTB, Sophia Antipolis.
6. Angioletti, R., Gobin, C., Weckstein, M., Durand, E. (9-12/6/1997) 24 criteria for designing and constructing buildings with a sustainable development approach. *2nd International Conference on Buildings and the Environment.* CSTB-CIB, Paris.
7. CSTB (18-19/4/1996) *Sustainable development and the future **of** construction - Phase II - Sophia Antipolis Meeting,* CSTB, Sophia Antipolis.
8. CSTB (18-20/11/1996) *Sustainable development and the future **of** construction - Phase IIIa - Bucharest Meeting,* CSTB, Sophia Antipolis.
9. CSTB (5-6/5/1997) *Sustainable development and the future **of** construction - Phase IIIb - Brussels Meeting,* CSTB, Sophia Antipolis.
10. CSTB (7-9/10/1997) *Sustainable development and the future **of** construction - Phases IIIc & IV - Budapest Meeting,* CSTB, Sophia Antipolis.

CIB World Building Congress 1988
Gävle, Sweden, 7-12 June

Open Building Implementation
Matching demand and supply for flexibility

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Abstract
Open Building provides strategies for consumer oriented and sustainable buildings and neighbourhoods, based on specific principles and methods in programming, design, production planning, construction and facility management. Open Building inables built environments to adjust, meeting changing social, environmental and technical requirements.

Many office blocks are unoccupied because they no longer meet present requirements. Installations in particular often prove not to be sufficiently flexible to follow changes in their use without too many adaptations. It is expected that in this sector there will be an increasing lack of occupancy in the coming years. This tends to lead to demolition and new-construction projects and to considerable wastage. Such activities not only involve a destruction of capital, but they also have an adverse effect on the environment. What is needed to avoid vacancies is the possibility of adapting buildings to the rapidly changing demands of users. The technical installations are often found to be the key factor with respect to the possibilities of adapting buildings. However, the demand for greater flexibility in buildings, and hence in installations, does not arise from economic considerations only.

Developments in the building sector show a number of trends all of which point to the growing importance of flexibility in buildings and installations. In addition there is the trend towards durable building. Environmental problems and energy management are very much in the limelight. Recyclability and sustainable buildings will be major criteria in judging future buildings. Among the factors that play a role here are saving of base materials, minimizing waste production, ease of dismantling, adaptability and deposit money arrangements. Clearly, flexible buildings that are readily adaptable to changing conditions respond to this trend.

Conclusions
A method called Flexis has now been developed whereby a detailed picture is obtained of the flexibility demanded and offered. Flexis enables the parties involved in the realization of a building to communicate about the flexibility of that building and its installations in relation to each other. The Flexis method can be used to judge the various flexibility aspects of existing buildings and their installations, but also to formulate the requirements with respect to flexibility when new buildings are to be realized. Thus, Flexis forms a means of communication on both the supply and the demand side of the building market.
Keywords: Open building, sustainability, flexibility profile; installations, partitionable, adaptable, extendible, multifunctional.

1 Introduction

The design of flexible installations in commercial and industrial building is very much an optimization problem, in which the building and the installations are inextricably bound up with each other. For a ready adaptation to market fluctuations it would be desirable to impose the condition that the building, along with its installations -in various combinations- should be suitable for several uses. And this should be borne in mind already during the development phase.

The development of a vision with respect to the flexibility of a building, or of a flexible-building concept, should therefore go hand in hand with the development of an associated flexible-installation concept. In fact, it is recommended to integrate the design of a building and that of the installations at the earliest possible stage. of development.

1.1 Alter or move

Hundreds of millions of dollars are spent annually in Holland on the alteration of buildings, but these efforts often fail to generate optimum work situations. Alterations involve not only considerable expenditure but also nuisance, both direct nuisance caused by the reconstruction and indirect nuisance resulting from temporary inefficiency of the work situation. Owing to the flexibility of their accommodation being exhausted, or through the absence of flexibility, businesses tend to reach the limits of their growth much sooner than is permissible in the light of the depreciation schedule. Spatial and technical adaptations in buildings are unavoidable and structural.

This means that in the case of a change in task or in mode of oneration it must be possible to adapt the accommodation" to the new functional requirements. The following diagram roughly indicates the steps that can be taken when a building no longer meets the requirements imposed by its use (figure 1).

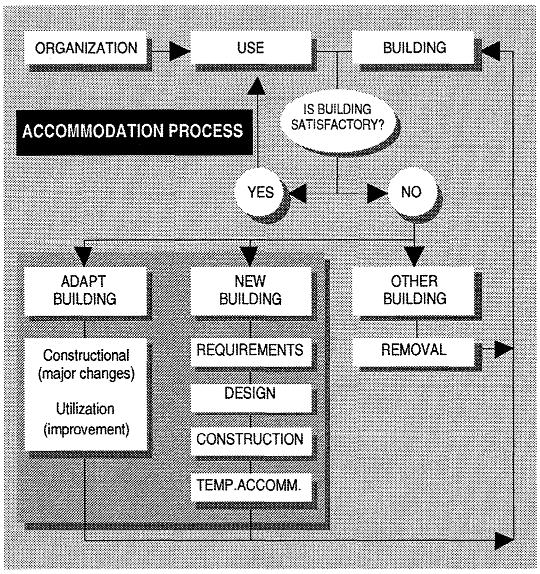

Figure1 Steps to be taken in the accommodation process when a building no longer meets the requirements; shaded area indicates the essence of Flexis

Three options are open to an organization: adapting the existing building, constructing a new one, or moving to another building [1]. Flexis is not concerned with the latter option. But adaptation of an existing building or erecting a new one are two possibilities that can be considered with Flexis.

2 Installation systematics

During the development of Flexis the need was felt of setting up a consistent system for the description and determination of technical installations in buildings. The methodical description of installations is based on the functions they can perform. This makes it possible to formulate project- and product-independent performance requirements and to compare project- and product-bound technical solutions with the performance requirements.

By a functional installation concept is meant the project- or product-independent formulation of the installation functions wanted in a building. It is a formulation of the demands to be met and it finds application mainly during the programming phase of projects. Installation systems are project- and product-independent technical solutions fitting an installation concept. For each installation concept (= demand or performance requirement) various technical solutions or installation systems can be formulated and offered (= supply). Installations are specific product and material configurations the components of which have been specified and which are the tangible form of the installation system previously formulated. An example is a mobile air conditioner of a certain make. At the level of the greatest detail each installation can be subdivided into various components. To meet the need for clustering and generalization the Flexis method distinguishes five kinds of components: user-interface facilities, measurement and control facilities, distribution facilities, production units, supply and removal facilities and constructional facilities.

2.1 Installation levels or modularity

Modularity refers to the various spatial levels at which the installation functions are in operation or are offered. Within the framework of Flexis two major levels are distinguished: the local and the central level (see figure 2). The central level is the set of all the levels higher than local. In a building these are a floor, a wing and the whole building. Examples of installation facilities at these levels are central supplies or central units and main distribution channels. In general it can be concluded that the flexibility of an installation is determined to a considerable extent by the (spatial) level at which that particular function is offered.

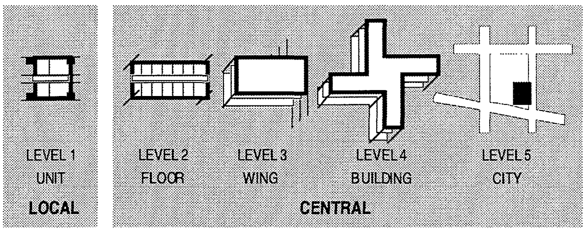

Figure 2 Various levels at which installation functions can be offered

3 Flexibility

Flexis distinguishes four aspects of the flexibility of installations in buildings: partitionability, adaptability, extendibility and multifunctionality.

Partitionability is the possibility of splitting up, rearranging or combining installation systems into different spatial units in a simple way. An important point in this connection is whether distribution, conversion, supply (transfer) and the measurement or control of installation functions take place locally or centrally. Another important aspect is a possible distinction between the collective (support) and the individual (infill) mode of offering functions and the zoning of distribution facilities.

The adaptability of an installation is the possibility of altering installation systems in a simple way to meet changes in the user's demands (the installation function required) resulting, for example, from a structural or functional rearrangement of the building, from changes in use, the coming of other (groups of) users, or technological renewals and modernizations considered necessary.

Extendibility is the possibility of adapting installation systems in a simple way to additional user demands, for instance by the addition of more or new installation components called for by structural or functional extensions, both inside and outside the existing building.

Multifunctionality is the possibility of using or deploying installation systems or components for several functions. This allows of a more efficient use of space and permits clustering and concentration of installation components. This concept is sometimes also called integration.

3.1 Assessment aspects of flexibility

In order to judge the flexibility of building installations or their components, each flexibility aspect is divided into a number of subaspects (see figure 3).

ASSESSMENT ASPECTS OF FLEXIBILITY	
PARTITIONABLE	1 DISTRIBUTION (+) supply 2 DISTRIBUTION (-) removal 3 CONVERSION (central unit) 4 TRANSFER (functions) 5 MEASUREMENT 6 CONTROL
ADAPTABLE	7 DISCONNECTIBLE 8 ACCESSIBLE 9 ADJUSTIBLE
EXTENDIBLE	10 CAPACITY (local) 11 CAPACITY (central) 12 DIMENSIONS (distribution) 13 LOCATION (shafts)
MULTIFUNCTIONAL	14 INTEGRATION (functions) 15 UNIVERSAL (components)

Figure 3 Aspects used in judging the flexibility of installations

4 Judging partitionability

Figure 4 shows what is meant by the assessment criteria for the flexibility aspect called partitionability. It comprises the subaspects of partitionability: distribution (supply and removal), conversion (central unit or supply facility), transfer (of installation functions), measurement (consumption) and control (use).

4.1 Partitionability criteria, weighting factors and score

In figure 4 three possible ratings (3=positive, 2=neutral, 3=negative) are given for each assessment aspect of partitionability. In addition, different weighting factors are introduced for the assessment aspects (5=very important, 4=important, 3=fairly important, 2=hardly important). The rating multiplied by the weighting factor gives the partitionability score.

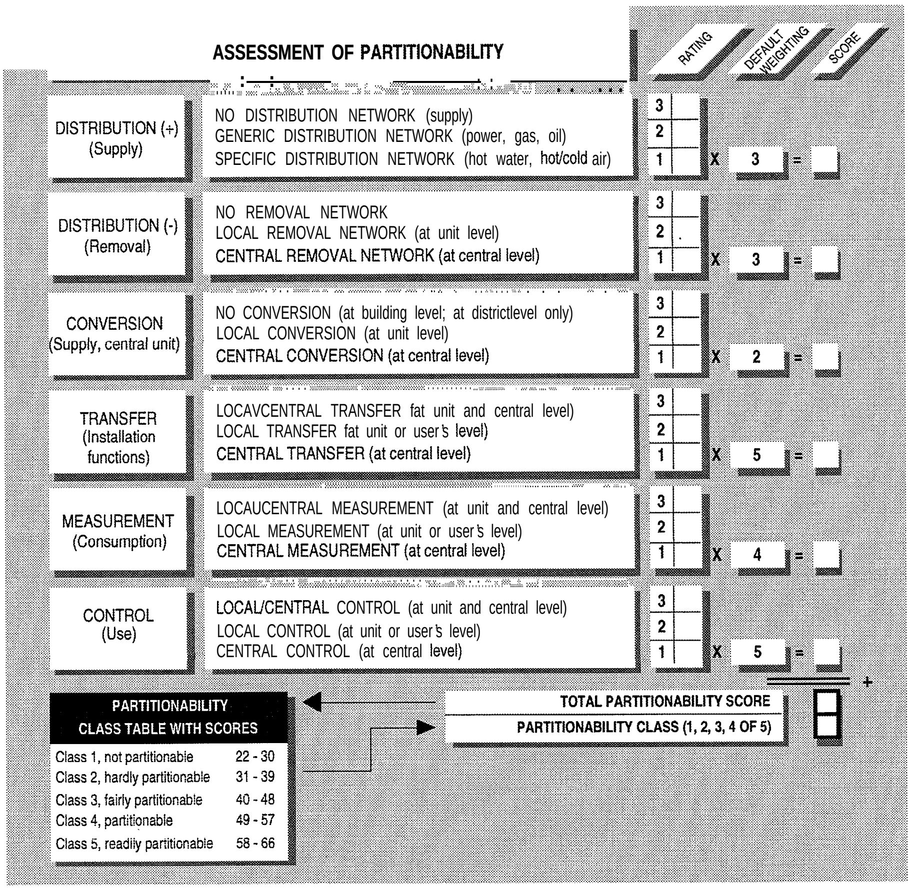

Figure 4 Criteria and weighting factors used in judging partitionability

4.2 Partitionability class

Thus a final judgement can be given as to the overall partitionability. It is the weighted partitionability score of the installation system concerned that comes within a certain score range. This score can be expressed as a partitionability class and can be found in the relevant table.

5 Judging adaptability

Figure 5 shows what is meant by the assessment criteria for the flexibility aspect called adaptability. For this purpose three subaspects of adaptability are used, disconnectibility (installation components), accessibility (also components) and adjustability (measurement and control).

5.1 Adaptability criteria, weighting factors and score

In figure 5 three possible ratings are given for each assessment aspect. In addition, different weighting factors are introduced for the assessment aspects. Ratings multiplied by weighting factors give the adaptability scores.

5.2 Adaptability class

Thus a final judgement can be given as to the overall adaptability. It is the weighted adaptability score of the installation system concerned that comes within a certain score range. This score can be expressed as an adaptability class and can be found in the relevant table.

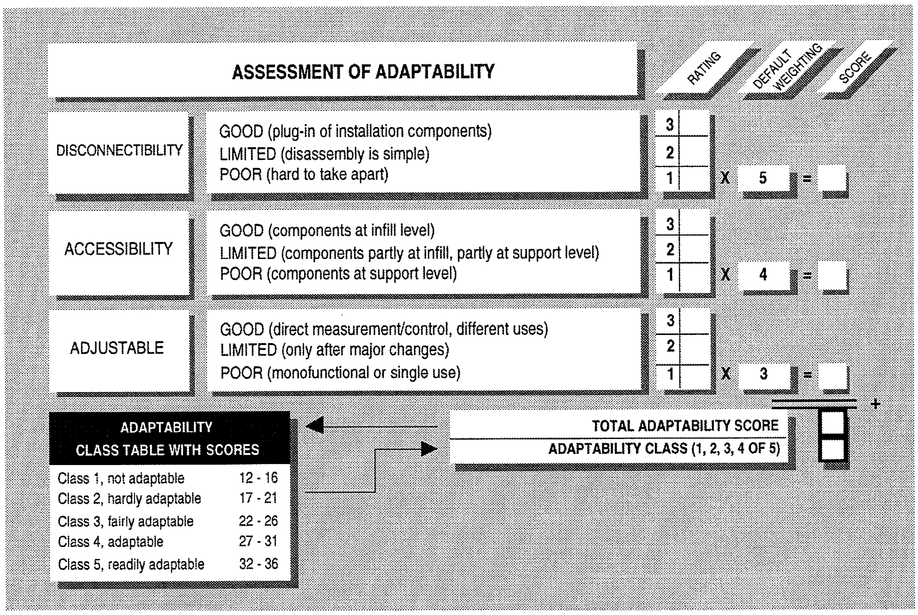

Figure 5 Criteria and weighting factors used in judging adaptability

6 Judging extendibility

The diagram below shows what is meant by the assessment criteria for the flexibility aspect called extendibility. For this purpose use is made of three subaspects of extendibility introduced earlier, capacity (of the supply facilities, both local and central), dimensions (distribution networks) and location (ducting shafts and zones).

6.1 Extendibility criteria, weighting factors and score

In figure 6 three possible ratings are given for each assessment aspect of extendibility. In addition, different weighting factors are introduced for the assessment aspects. The ratings multiplied by the weighting factors give the extendibility scores.

6.2 Extendibility class

Thus, a final judgement can be given as to the overall extendibility. It is the weighted extendibility score of the installation system concerned that comes within a certain score range. This score can be expressed as an extendibility class and can be found in the relevant table.

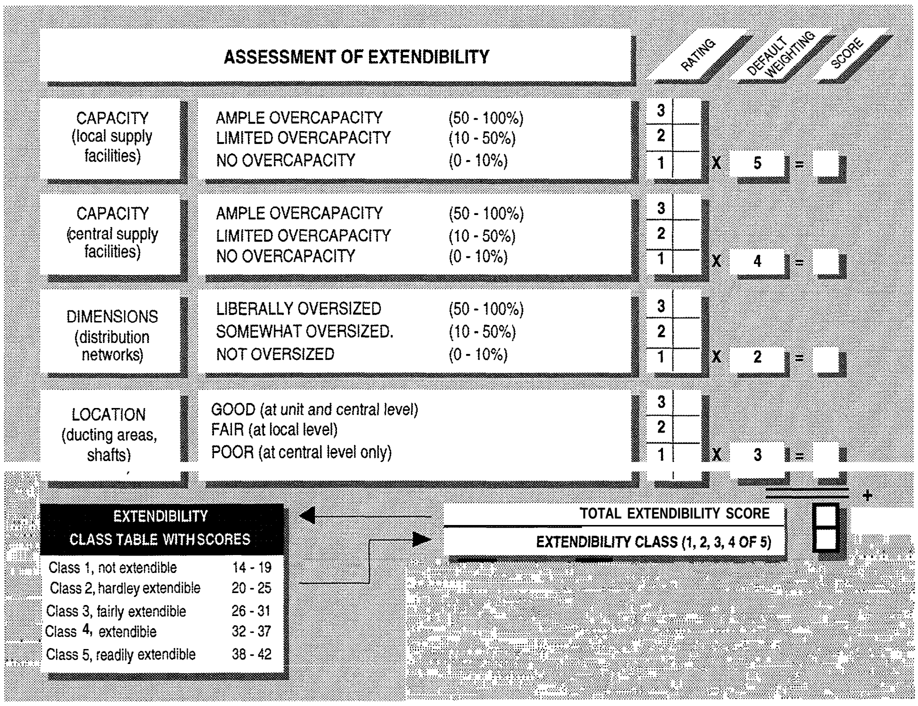

Figure 6 Criteria and weighting factors used in judging extendibility

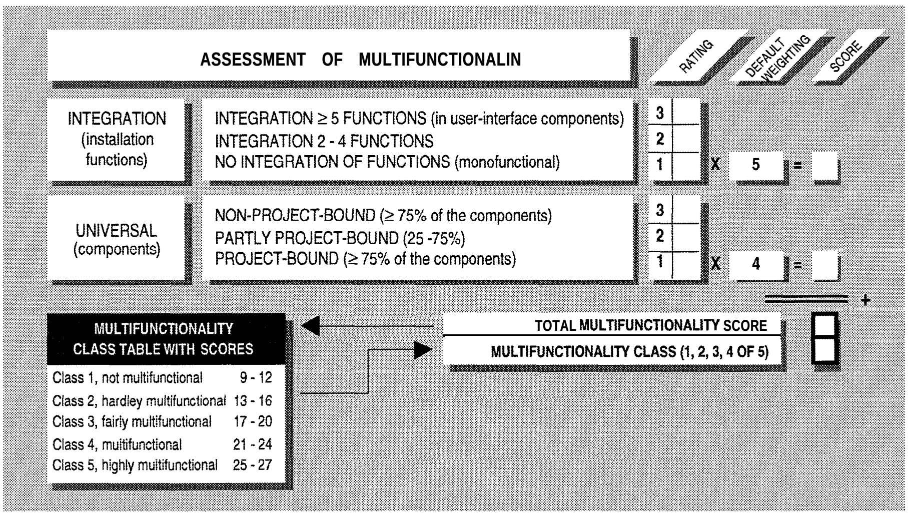

Figure 7 Criteria and weighting factors used in judging multifunctionality

7 Judging multifunctionality

The last aspect used in assessing the flexibility of installations is multifunctionality. A multifunctional installation or component can be used for several purposes. It permits a more efficient utilization of the available space and enlarges the ductless area through clustering and concentration. Another aspect that plays a role in the assessment of multifunctionality is the extent to which a system is universal.

In figure 7 three possible ratings are given for each assessment aspect of multifunctionality. In addition, different weighting factors are introduced for the assessment aspects. The ratings multiplied by the weighting factors give the multifunctionality scores. Thus, a final judgement can be given as to the overall multifunctionality. It is the weighted multifunctionality score of the installation system concerned that comes within a certain score range. This score can be expressed as a multifunctionality class and can be found in the relevant table.

8 Judgement of overall flexibility

In the foregoing we discussed in detail the criteria used in judging the various flexibility aspects: partitionability, adaptability, extendibility and multifunctionality. Similarly, at a higher level, the overall flexibility of an installation can be determined. Here, too, weighting factors, scores and flexibility classes have been developed. To record the outcome of the flexibility assessment of installation systems or their components, a special assessment form has been designed.

8.1 Flexibility profiles

For a direct comparison between different installation systems use c.an be made of the calculated flexibility classes. But this approach does not at once show which is the most important aspect of flexibility. With one system emphasis may be on partitionability, whereas with another it may be on the extendibility of the installation. To make this clear at a glance, we can draw what is called a flexibility profile.

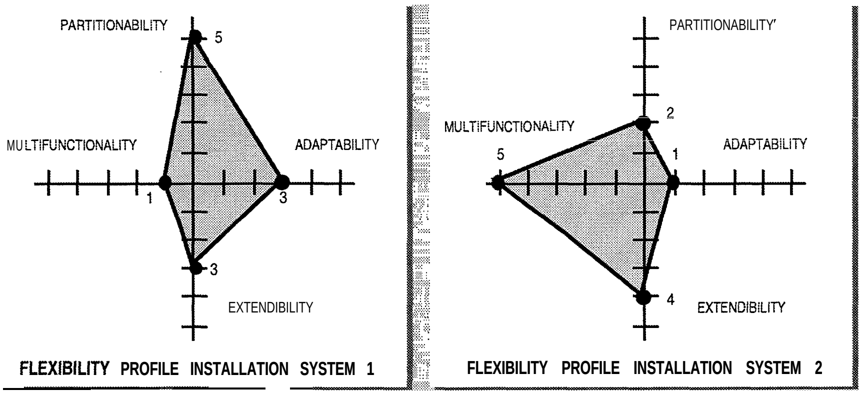

Figure 8 Two examples of flexibility profiles of installation systems

In the flexibility profile of installation system 1 (see figure 8) the partitionability score=5, the adaptability score=3, the extendibility score=3 and the multifunctionality score=l. Together they represent the total flexibility score (the shaded area). In this way different installation systems can be easily compared by graphic means.

Acknowledgements

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References

1 Dekker K.H., Nicolaï, *Flexibiliteit als bouwstrategie,* Nationaal Ziekenhuisinstituut, The Netherlands, 199 1

A centre for sustainable housing technologies in Brazil

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Abstract
This paper addresses the supporting ideas and main proposed activities governing the implementation of a sustainable low cost housing development to be built in the State of Rio Grande do Sul, (southmost State of) Brazil. The housing development is proposed to become an *Experimental Centre for Sustainable Housing Technologies,* with the aims of demonstration, research, and education, directed towards students, professionals, researchers, concerned public authorities and the public in general. A Brazilian institution (FINEP) will be funding the author to lead an interdisciplinary team in a research project, about to be started, to further develop the best ideas presented in an international design ideas competition, *Sustainable Housing* ***for*** *the Poor,* that was also organised by the Federal University of Rio Grande do Sul.

It is estimated that by the end of this millennium the Brazilian population will be around 180 million, and the lack of housing, between 5 and 12 million, according to different sources. No prospects are seen for a quick change in wealth distribution in such a wealthy country, with abundant natural resources. How far housing is concerned, the tendency is to keep providing poor people with the existing type of poor quality solutions, that are also related to poor environmental management.

The project proposal described in this paper illustrates the work the interdisciplinary design team associated to the project intends to develop in order to create healthy and comfortable housing solutions, at an affordable cost, with minimised environmental impact. In a first stage the funds to be allocated to the project will be devoted to fully develop the architectural and urban planning design of the Centre, that later will be implemented and then monitored (future stages of the whole research project).

The main issues, that will challenge the interdisciplinary design team, include: use of renewable energy sources; solid and liquid wastes management; use of building materials with low environmental impact; creation of productive landscape, for food production; and social and educational issues.
Keywords: demonstration centre, low cost housing, sustainability.

1 Introduction

At the start of a new millennium, some considerations are due regarding the environment we are building, and, in particular, the Brazilian situation. Estimates for the year 2000, tell that the Brazilian population will be around 180 million, 80% of which will be living in urban areas. The prospects point out to a worsening of the present problems, including that of a worsening of the income distribution among the population, where the present numbers show that 50% of the economically actives have a monthly income of less than US$ 200.

Unless there is a considerably shift in the present tendencies we hardly will see any modification in the following expectations:

- The increase of unemployed or badly paid people, living in favelas, under the bridges, in installations occupying the sidewalks of the cities or in dry litter collectors used during the day as a working tool and during the night as a place where to rest. These conditions, associated to a famished or badly nourished and unhealthy population, stimulate the development of a proper environment for the intensification of violence, crime, drugs dealing, etc., that characterise the daily routine of many Brazilian cities.
- The increase of all sorts of pollution, that include, in the big cities, the air and noise pollution determined by the traffic of vehicles; the solid and liquid waste disposals, generated in volumes much above the assimilation capacity of nature.
- The irrational energy consumption patterns, associated to the exhaustion of non-renewable energy sources.

The cities of the next millennium certainly will not need to be like this. They only will be so, if we continue to leave them grow in a disorganised manner or contribute towards their growth according to the present model, that is clearly not sustainable. To make them sustainable, we have to redesign them, including them in a global context of sustainability, extending this redesigning beyond the boundaries of the urban tissue, including the treatment given to rural areas and to society on its whole. Each detail of this whole, nevertheless, has to be carefully planned.

On this way, when we think about low cost housing schemes according to a sustainable model, including them in a larger context, we must consider not only the housing unit that will constitute the family's home, but the whole where this unit will be just a part, and, stepping through the several scales, the relationships established between this unit and the whole environment.

We will, then, also be dealing with matters like: the production and treatment of wastes generated by each of the housing units (as well as with the whole of the units) and the alternatives for obtaining water and energy for different uses. Within this larger context, one can not forget the issues related to the individuals' health, that is directly connected to his food, to the quality of this food, that, on its turn, depends on the way the same food is produced. The way people move must also be rationalised, in such a way to minimise the time wasted on transportation, as well as the associated pollution and energy consumption. This way, each person would be able to use their time and energy in a more clever way, either by increasing the time spent with the family and friends or by providing themselves more time for activities more closely related to their interests.

An interdisciplinary research project is being started, co-ordinated by the Department of Civil Engineering of the Federal University of Rio Grande do Sul, aiming at the implementation of an experimental housing settlement, to be built in accordance to sustainable principles. The whole project includes the development of a full architectural project, its implementation and a post occupancy assessment.

2 The Design Ideas Competition

The architectural project, to be started now, will follow the guidelines defined by the results of an international Design Ideas Competition Sustainable Housing for the Poor, organised by the Federal University of the State of Rio Grande do Sul and sponsored by ANTAC (Brazilian Association of Technology for the Built Environment) and PLEA (Passive and Low Energy Architecture).The main aim of this competition was of *stimulating the presentation of design alternatives on architecture and urban planning compatible with the Brazilian reality and the principles of Sustainable Development.*

The experimental housing settlement is to be built either in the city of Alvorada, with a large population of very poor people, or in Porto Alegre, the capital city of the southmost (30ºS; 51ºW) state of Brazil. Porto Alegre has a population of about 1.5 million inhabitants, although the Great Porto Alegre, where Alvorada is located, has about a million more.

Porto Alegre has the advantage of being one of the most ecologically conscious cities in the country (and this is mostly due to Jose Lutzemberger, an alternative Nobel prize winner for his fights and contributions to the environment preservation in the State and in Brazil, in general, since the early 70’s). Strict pollution control legislation are under way to try to recover the quality of the water of a large estuary that defines one of the borders of the city; there is a exemplar system of solid wastes collection and recycling now covering all areas of the city. Besides that, there is a growing demand for organically grown fruits and vegetables, in general. These are marketed in several shops, but mainly through a consumers’ and producers’ co-operative that also organises a very popular weekly street market and that strictly controls the quality of the marketed products.

The also called *production village* is envisaged to be organised in such a way to supply not only housing for the poor, but also job opportunities for people, primarily with an agricultural background. This background will be interesting not only for selecting people able to manage their vegetable gardens and from that to be able to achieve a minimum life sustainability, but also as a possibility for creating new jobs, once they are organised, as planned, as a producers’ co-operative, with the aim of producing organically grown fruits and vegetables for supplying the surrounding cities population demands.

2.1 Housing scheme

The housing settlement was devised to have twenty houses (a scale small enough to be easily manageable) and a social/educational centre, for diurnal education of the youngsters and nocturnal education of the adults, giving also options for other social activities for the whole community. Each house is expected to be surrounded by a sufficiently large domestic orchard to supply the food demands of each family (fruits, vegetables, poultry, etc.). This orchard will also give an opportunity for creating the desirable microclimatic conditions for the local built environment, that has to face hot weather in summer and fairly cold and windy weather in winter.

As far as possible, the design will present alternatives for diminishing the demands on externally supplied energy sources and for the recycling of the domestic and community wastes.

Also, the building site will be chosen in, such a way to make underground water available for domestic consumption and for vegetable production including also the provision for collection and reservation of rain water.

2.2 The housing units

The construction of the individual units will make use of locally and traditionally accepted building materials, including timber and bricks or blocks of several origins (like clay bricks, soil-agglomerant, etc.).

The houses will be designed in such a way to accommodate a family, with a minimum area of about 40 m^2 (new houses for low income people in Brazil have been built with an area of less than 25 m^2)and making allowance for future expansion. As a general guideline, a target budget of 150 to 200 US\$/m^2 for the construction of the houses (in addition to the labour of the futures users) is being taken as a reference.

The school/social centre is going to house a maximum of 100 children/adults in two classrooms, convertible into one large single room.

The construction plot will be chosen to be located within a radius of about 40 km from Porto Alegre's city centre and well supplied with potable underground water, with a total area of 10,000 m^2.

2.3 The results of the Design Ideas Competition

The above mentioned competition, that will lead to the development of the final project, was open to students of architecture and allied disciplines, as well as to architects, world wide. Team entries were encouraged.

The Organising Committee received 38 submissions, being awarded 6 prizes: 3 to professionals and 3 to students. From the 38 entries, 6 were submitted by professionals and 32 by students.

The prizes, totalling US$ 6,000.00, were announced on the 7th July 1995, at a ceremony held at the end of the Conference.

The results of the competition and respective prizes were as follows:

- *Professional track:* 1st prize (one sheet of the set submitted to the competition is shown in the next page) - Michael D. Morrisey, H20 Workshops, Australia - US$ 2.000,00;
- *Student track:* 1st prize - Nigel J. Craddock , The Martin Centre for Architectural and Urban Studies, University of Cambridge, UK - US$ 750,00.

3 The research project

The research project to be developed intends do create a Research Centre for new technologies related to social housing, incorporating, on the one hand, the principles of sustainable development, and on the other hand, the idea of housing as the habitat of man in the social context.

In this way, housing is **the** end, discarding such concepts that sees housing as a way of reaching an economical balance, promoting the civil construction industry as the main protagonist in solving the unemployment problems, the so-called low qualification of labour, the need for urban expansion, etc. On the above mentioned way, the laboratories for the study of housing technologies could ignore the user, limiting their scope to such subjects like the production of low cost and easy to use materials and, much probably, concentrating efforts on restricted areas or specific to product conception.

Thus, starting from the idea that the dwelling is the locus for the reproduction of labour, it is believed that the function of housing is beyond that of a simple protection, but incorporates all the processes of health, education, protection, enjoyment of life and relationship with the social and natural environment. Therefore, the conception of the laboratories, basically, assume the existence of a Research Centre where the urban way of life could be analysed as a performance assessment parameter of the presented proposals. The production and implementation of the projects could be followed by monitoring where the processes, products and recommended performances could be assessed in a larger context considering multidisciplinary interferences, including social, technical, environmental, cultural issues, among others.

The project as a whole will be developed in four stages:

- Modelling and projects development;
- Implementation and occupation
- Monitoring
- Product development

The modelling and projects development phase will include all the stages relative to the planning of the physical infrastructure and functional support to the activities to be developed locally. These include the land survey, the zoning project, the development of architectural projects for the houses and other buildings, including also water and energy supply, sanitation, communications, etc. On the way this work is being conceived, we also consider in this stage, agriculture projects, for local food production (permaculture, aquaculture, cornposting, etc.), alternative projects for solar and wind energy collection, rain or underground water collection, liquid and solid wastes management. Considering that in the general project there is the intention of keeping people as close as possible to the living area, among the proposed proposals alternatives for job and income generation should be assessed.

Once the modelling and projects development phase is concluded, the implementation and occupation of the site will start. As the built environment production process will be of self-building, some qualification and training courses should be conducted during this phase. The construction work management will provide the project team the feedback to adequate the adopted project technology to the reality defined by the local availability of materials and workmanship, as well as to the users' requests.

The next phase, the monitoring, that is expected to last for two years, will be followed by the technical team, starting by the occupation of the dwellings by their users, having the implemented proposals assessed. The main aim of this phase is to generate indicators for the assessment of the proposed technologies, considering the social-environmental impact they produce, besides allowing a comparison between the traditional solutions and the alternative proposals.

The final phase of the project of products development, where after the assessment and the check of the real possibilities for the developed products to be absorbed by the market, new projects could be developed to make these products available, using the infrastructure of the productive sector.

4. Discussion

Both the future implementation of the Centre, as its operation after completion, will require the participation of multidisciplinary teams from several institutions. Once concluded the project, the effort of the different contributors certainly will be rewarded by the opportunity, perhaps unique in the South American continent, of having aggregated in the same place, a whole series of environmental strategies that, usually, are only partly developed and applied in different places. Even more important is the attachment of the project to the Brazilian social reality, and the expected results to be obtained through the project, not only the technical results, as those of organisation and mobilisation of the involved target groups, that will enable the offer of alternatives to present critical situation.

The proposed Centre, if successful, will be a consultation reference for a wide public:

- To those interested in Sustainable Buildings, the houses and other buildings in the Centre, built basically with the use of local low cost materials e low embodied energy, besides having the participation of the future users, will offer a opportunity to verify the application of bioclimatic architecture to low cost housing, like the natural conditioning of buildings, and, if possible, the use of solar energy for water heating, as well as of the other sustainable construction techniques to be used;
- To those interested in Sustainable Agriculture, there will be the garden and orchard that will feed the residents, including a variety of plants cultivated according to sustainable management techniques;
- The liquid and solid wastes management systems, will identify new possibilities for wastes treatment with no environmental damage;
- In such an integrated and balanced system the domesticated animals also should integrate the site, accomplishing their recycling functions and providing proteins to the residents. Chickens, pigs, fishes, bees, ducks and goats, as well as other animals, might be introduced into the site, where useful information on sustainable ways of keeping these animals will be made available.

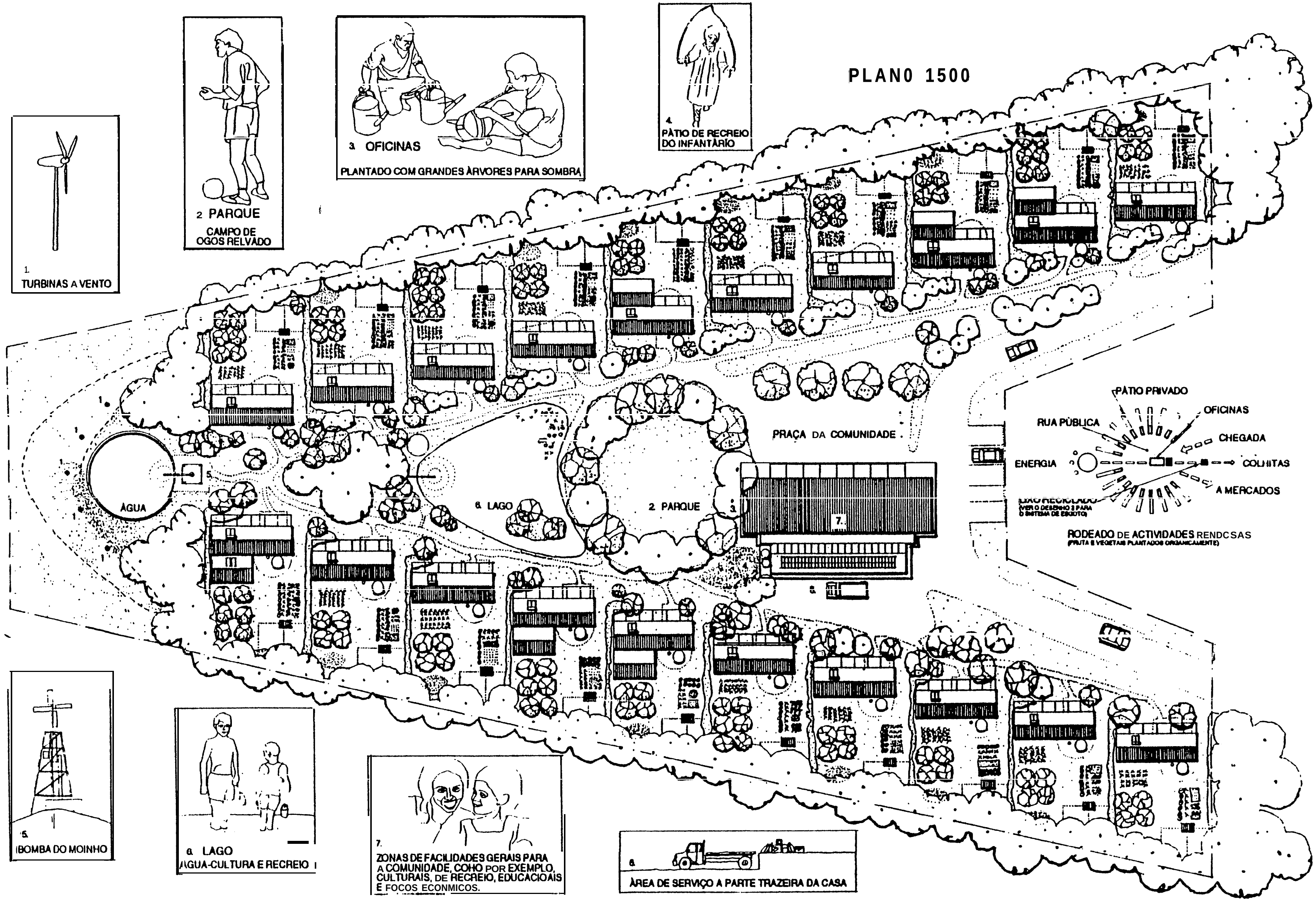
With its proposals of education, demonstration and research, the Centre, in the project development stage and, probably, through its normal operation in the implementation stage, will supply to the society a better understanding of subjects related to sustainable development, like:

- ENERGY: As far as possible, the Centre will try to provide their energy demand through the use of local resources. The buildings will use passive solar techniques. Biological systems will process the residues to produce methane gas. PV systems and wind turbines might be installed to produce electricity.
- BUILDINGS: The architectural shaping of the Centre will match the following aims: integration with the environment, use optimisation of the available energy and reinforcement of the social interactions.
- FOOD: Particular attention will be given to practices that: protect and enhance the soil characteristics; reduce energy consumption and the use of fertilisers and other chemical products; maximise the possibilities of multiple use and reduce water consumption;
- WATER: An integrated system of water flow will allow the research and demonstration of techniques like aquaculture, irrigation and the biological treatment of waste water;
- RESIDUES: Through a rational operation, the Centre will minimise energy and materials consumption, that will also minimise residues. From the unavoidable residues, the organic material might be reintroduced into the local ecosystem. The kitchen residues might be used for feeding animals, while other residues might be composted or receive a biological treatment for methane gas production.

3. Conclusion

Although the implementation of the winning scheme, as an *experimental centre* for demonstration, research, and education, is still a goal to be achieved, this is under way now, with its design stage to be started in the coming months. But while that does not start, the dissemination of principles for the design of sustainable communities has been made continuously, through exhibitions and talks regarding the competition's results.

Anyone looking at the existing housing sites in Brazil, realises that ***nature*** has not been taken into consideration when they were designed, and, what is even more worrying, little attention has been given to ***life,*** in general. It is hoped that the implementation of the Experimental Centre for Sustainable Housing Technologies will serve as reference to new housing developments in Brazil.



PLAN0 DA PROPRIEDADE

ALDEAMENTO EXPERIMENTAL DE PRODUÇÃO RURAL
PORTO ALGERE, BRASIL
ANTAC/PLEA COMPETIÇÃO DE IDEIAS SOBRE DESIGN
Design by Michael Daniel Morrisey D May 1995

P O Box 257 Pyrmont 2009 AUSTRALIA
H2O workshops
DESIGN E CONSTRUÇÃO

1

Design for Adaptability
- a hierarchical decision process for adaptability

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Abstract
In both business and in the building process, we experience a development away from stable and linear processes, towards more change, shorter innovation cycles and constantly ongoing adaptations to changes in the environment. This demands a higher degree of adaptability in buildings and in the design- and construction process. At the same time as organisations change more rapidly, some corporations have started to consider how their offices support their business, and if the facilities allows the organisation to work efficiently.

This paper presents an approach for designing adaptable office buildings. The high rate of change makes it necessary to be able to start development without having defined the objectives and specifications at the most detailed levels. Decisions in the planning process are being pushed forward, so that the just-in-time concept applies for decision-making as well as production. The design team has to cope with changes at all times during the process. One way of coping with those changes is to develop a hierarchy of plans, each with its own time scale. This paper describes a hierarchical approach to design- and decision-making based on to the technical and functional life spans of the building. Adaptability and reuse of buildings can, ideally, save resources. This paper also deals with how adaptability influences the economy related to office buildings.

Our understanding has been developed during research projects, where in-depth case-studies have been used to address these issues. The paper will therefore use ***Dagbladet*'s** renovation project in Oslo as a case to present the hierarchical decision process which can be used to improve design for adaptability. ***Dagbladet*'s** primary goal was to continue to be located in Akersgata, which houses the largest newspapers in Norway. In order to do this they had to adapt the existing buildings, which were far from ideal for flexible, modern offices. In order to cope with this difficult situation, they implemented a flexible and strategic planning process, a layered decision process. The physical steps taken to solve this problems are based on traditional techniques like flexible partitions etc. What is interesting about the case is that to be able to adapt the existing buildings, they focused on the ***process of making,*** on strategic planning and decision process, and not only on the physical solutions.
Keywords: Design process, Adaptability, Life-cycle perspective

1. Introduction

Today's businesses face a rapidly changing environment, due to changes in the markets, in technology and international competition as well as a shift towards more knowledge- and information-based services. To survive in this changing environment, businesses themselves have to innovate, adapt and change.

As businesses change faster, so will their functional and spatial requirements. This leads to changes in office buildings, as well as to where and when people work. Buildings are solid, and more difficult to alter. Once erected, they are expected to last for decades, in some cases even centuries. This means that to meet the challenges posed by businesses, buildings must be adaptable.

Adaptable buildings are more than just «flexible». During the last 25 years the word «flexibility» has been used to characterise almost every office building. Some of them have proved themselves to be very successful, others not. For many clients, the extra cost of building in modular systems for flexible partitions and technical services has proven to be too high compared to the resulting flexibility in use. What is designed to be flexible, might prove to be inflexible in use. It is hard to predict where and how the changes will occur.

This paper will focus on adaptability of office buildings, because most of our cases are of that type. A Norwegian case study, the renovation of the newspaper ***Dagbladet***, will be used to illustrate one strategy that can be applied in order to design more adaptable buildings; a layered decision- and design-process, which we have called «the decision hierarchy)).

2. Design for Adaptability

In order to structure our discussion we have used the following definitions for «design» and <<adaptability>>: By «design» we not only mean architectural design, *but the whole process of developing a project, and the decisions taken during that process.* The actual «design», according to the more narrow definition, is developed by architects and consultants, while most of the decisions regarding needs, finance, use etc. are made by the client or his representatives. These are different in character, but in this paper we will not discuss these differences further. Our aim is to look at the whole process of project development.

We define <<adaptability>> as *the ability to change, responding to changes in the environment.* When we consider adaptable office buildings, these changes are initiated by changes in:

- demand for organisational change, related to use (= functional requirements)
- technological innovation
- changes in the financial and contractional environment (Real Estate Market)

Changes in the environment challenges the adaptability of buildings. At the same time the building itself goes throught a change process related to the building's deterioration and technical decline. The gap between the level of performance and the increased level of expected standard (building quality, user expectations and legislation) widens as the building ages (se Figure 1).

We will describe «Design for adaptability)) as a strategic process, which must be developed and refined throughout the project. In order to design more adaptable office buildings, there are a number of *strategies that can be applied.* Some of these are:

- Adaptability and flexibility in the building (like flexible, modular partitions etc.)
- A flexible portfolio of buildings (the user moves when his needs change)
- Responsive management of the building(s)
- More flexible ways to use the building (e.g. free address offices)
- Adaptability in the process of planning, designing and managing office buildings

In this paper we will focus on the latter strategy, which is fundamentally different from the others, because it moves our attention from the product, the building, to *the process of making* the product. This is the entire development cycle of the building, which include both the briefing process (user and client needs), design, construction and Facility Management, building management, use and demolition. In our work we have described the building process as cyclical. An example is shown in Figure 1.

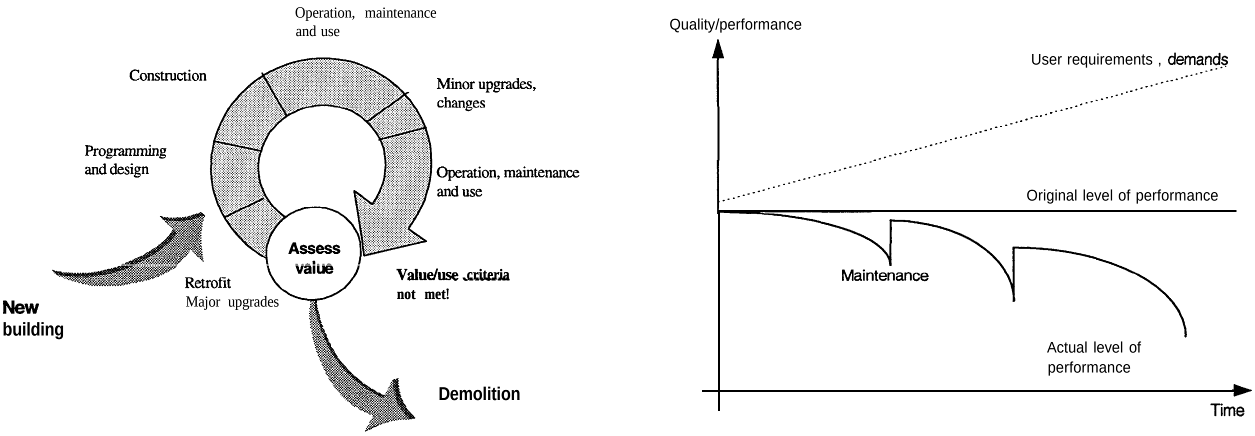

Figure I. The life cycle of an office building (left) and an illustration of the increase in demands in relation to an existing building's level of quality/performance (right).

2.1 The hierarchy

One way to deal with adaptability and changes in the planning process is to layer the decisions according to change rates and expected life span of each layer. This approach was used in the *Dagbladet* project, but before presenting their solution we will discuss this at a more general level.

When we divide the process into layers, each of these can be developed and worked out separately according to the development of the project. Long-term and strategic decision-layers can be decided upon early, and these will create a framework which the other layers have to be developed within. The detailed content of the different layers can differ and be project-specific, but some of the aspects that must be considered are shown in Figure 2.

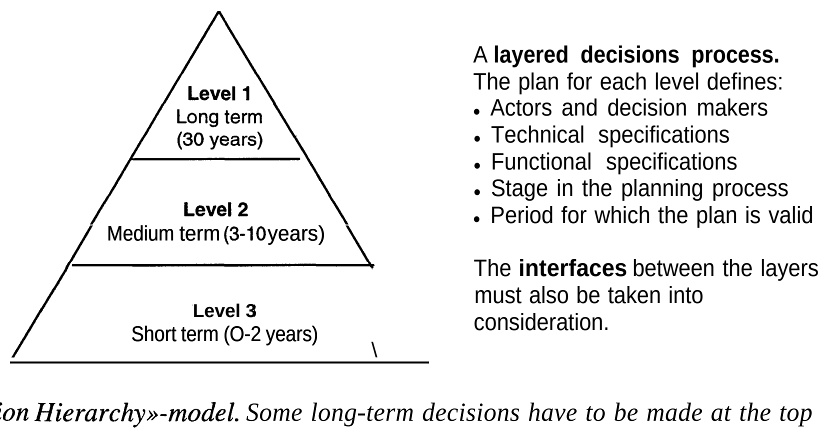

Figure 2. The «Decision Hierarchy»-model. Some long-term decisions have to be made at the top level. Within the limits of the long term plan, more rapid responses to changes can occur. At the bottom level, e.g. the floor plan, adaptations can be made from one day to the other.

In the following, we will look at some aspects of thelayered decision process, both in general and in the *Dagbladet* project. In part 3 we present the different stakeholders and a framework for implementing this in the design and planning process. We will also focus on the change process and on how the match between user needs and the buildings changes in time. Part 4 describes how the layers are defined according to service lives, considering both technical, functional and economical aspects. Part 5 shows the decision hierarchy for *Dagbladet* in more detail.

3. Changing user needs – adaptation as a two-way process

The organisation's needs change over time. In most cases, these changing requirements must be accommodated in a building. Organisations may choose to change location and move to another building, or the changes can take place inside the same building for a period of time. This is a two-way process, with adaptations in the way the organisation uses the space and with physical adaptations in the building.

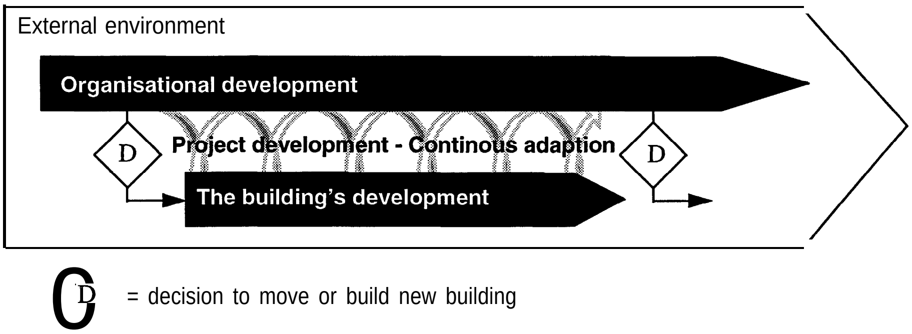

Figure 3. Both organisations and buildings develop over time. Between the building and the organisation there is a two-way process of continuous adaptation.

3.1 The match between organisational development and the building - Dagbladet

The newspaper *Dagbladet* has been located in Akersgata in Oslo since the 1950's. From the very beginning there has been more or less constant retrofitting and expansion of the buildings. We have mapped the retrofits and the changes in the buildings and in the organisation since they first moved to Akersgata. A schematic illustration of the development is shown in Figure 4. When we have investigated these changes, we find that they were instigated by new technology in the production of the newspaper and by new legal requirements regarding office work and work environments (Blakstad, Christiansen et al. 1997)

In the 1980's *Dagbladet* occupied three different buildings: the oldest from the 1890's, the others built during the 1950's, and they realised that more flexible and modern offices and larger areas were necessary.

After economic and environmental evaluations, *Dagbladet* decided to refurbish the buildings in 7 stages, with normal daily newspaper production going on simultaneously. The planning process started in 1993 and the first construction stage started in 1995. When the last construction stage was finalised in 1997, 7000 m² was retrofitted and 400 m² constructed as an extension to the *4.* - *6.* floor.

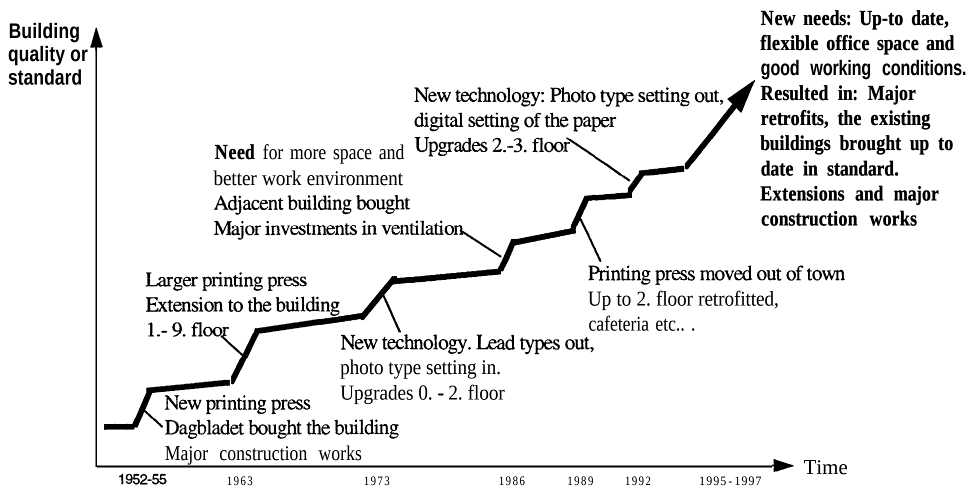

Figure 4. The development in Dagbladet's buildings in Akersgata.

The building's development and its suitability for the users are to some extent defined by its adaptability. In ***Dagbladet's*** case the different properties of the three different buildings became evident during the renovation. The building from the 1950's was designed to fit the demands of that time as efficiently as possible, and was very area-efficient when constructed. Its ability to fulfil today's demands were on the other hand much poorer than the ability of the building from 1890 (Blakstad, Christiansen et al. 1997). Low floor-to-ceiling heights and narrow modules between the windows were some of the problems that had to be solved by the designers. Even though this was given a lot of thought, and good solutions were implemented, you can still find many evidences of these problems in the new offices: too narrow offices, insufficient space for cabling and installations, and some floorplans suffering from fixed locations of meeting rooms and restrooms for smokers (these require more ventilation). These are examples of how physical constraints in the building limit the possibility for change.

3.2 Stakeholders and decisionmakers

In the decisions hierarchy, different stakeholders are involved in different layers of the decision process, trying to match the organisation's development and requirements with the building. The long-term decisions are the most strategic ones, and in *Dagbladet*'s case, the corporate, strategic management participated at this level assisted by the architect. The short term decisions are the ones that are most close to the end-users. It is at this level the need for adaptability and quick changes according to the work process is most needed. In the ***Dagbladet*** case, the decision makers at this level were department managers and end-users assisted by the interior architect.

4. Service life

The concept of hierarchy of decisions, which we have presented, is based on the layering of different parts of the building, according to their expected life-span. The different materials and components can be divided into groups according to their ***service life.*** Service life is defined as: «time during which an item remains serviceable)). The layers we will use for the hierarchy will be based on the expected service lives and the different layers' functions in the building. For this purpose we have used relatively broad categories. Our purpose is to develop a practical tool for planning, not a system to predict service lives of materials and components in the building. To develop this further into a generic approach we will have to consider both the logistics of the planning process and the service life of the layers.

4.1 The Physical Layers

In his work, Stewart Brand has defined 5 different layers (Brand 1994): Site, structure, skin, services, space plan and stuff. The example shown in part 5 does not follow this definition of technical layers. This is due to the fact that the grouping of decisions (on technical specifications) was both based on when in the planning and design process they were made, as well as on technical service lives.

4.2 The Functional Demands

In most cases, we find that it is the changes in functional demands that provokes change, not that the physical layer has reached the end of its technical service life. This is, of course, more true for the «internal layers» (services, space plan and stuff) which are closely related to use.

In many cases, the services layer is the most expensive to change. At the same time, this is the layer that constrains adaptability most. This means that in order to design adaptable solutions it is essential to co-ordinate design efforts and take into account both architecture, structural and technical aspects.

4.3 Cost implications and added economic value

Adaption and changes in buildings have cost effects as well as possible economical benefits. The economic service life of a building is the result of the balance between the building's and the component's technical life and the level of functional performance. When we study the cost effects of adaptability, we have to consider:

- Possible higher investment costs, due to more expensive, flexible solutions when constructing the building.
- Adaptable space plans are not always the most area-efficient (that effects both investment costs and costs-in-use)
- Renovation costs of adaptations and changes.

Adaptable buildings might also prove to be cost-efficient in the long run. This is due to:

- Reduced construction costs for future adaptations and reduced costs-in-use, compared to operating an unsuited building
- Possible gains in the efficiency of running the business and reduced risk of productivity loss due to renovation and adaptations (or at least for shorter periods).
- Reduced financial risk on investment

One example of this trade-off between construction costs and the costs of future adaptations are the calculations made for the *Dagbladet*-project. In order to obtain the desired level of flexibility, ***Dagbladet*** invested about 5000 NOK/m^2 in the retrofit. In the future, rearranging from cellular offices to landscapes will cost 200 NOK/m^2, and rearranging from landscapes to cellular offices will cost 500 NOK/m^2. The job can be finished in a night or a weekend. In order to make quick adaptations possible, they must not disturb the workprocesses in the newspaper. For ***Dagbladet, an*** uninterrupted production process is the most important of all economic considerations.

5. A Hierarchy of Decisions and Layers

For *Dagbladet*, one way of achieving the desired flexibility in their new offices was to accommodate a flexible design- and construction process. This fact became even more important because the renovation was carried out in 6-7 stages. While one part of the building was being renovated, other parts were still in the design phase. In order to do this, the two highest levels of the hierarchy were decided upon before the construction of the first parts started (Blakstad, Christiansen et al. 1997). The plans for the lowest level – the floor plans – were developed individually for each floor and department. This level can change very quickly, but the flexibility in this layer is dependent on the highest level decisions that are taken in level 1, the General plan, and level 2, the Master plan.

5.1 Level 1 - General plan

Contents	Functional specifications	Technical specifications	Participants, actors	Time frame
Strategic decisions Specification of demands	States the importance of flexibility Defines the vertical communication, location of stairs and lifts Defines a pattern for main horizontal communication paths Defines fire sectioning Defines and describes accessibility (for customers and for the disabled) Defines the location of specific functions such as main computerroom, filing, library etc.	Gives a record of loadbearing possibilities in the different buildings and floors Defines future shafts Specifications for acoustics and noise control Specifications for materials: floors, ceilings. Gives specifications for the modular partitioning system Specifications/descriptions of lighting, services and information technology & communication	Professional assistance: The Architect. Corporate top management CEO Project leader Steering committee	30 Years

5.2 Level 2 - Master plan

Contents	Functional specifications	Technical specifications	Participants, actors	Time frame
Locations within the building and functional demands	Location of departments in relation to each other to improve interaction and workflow Location of some special functions Demand specifications for some of the functions, area, number of people etc.	None	Professional assistance: The Architect. Department managers Union representatives Project leader	3 Years

5.3 Level 3 - floorplans

Contents	Functional specifications	Technical specifications	Participants, actors	Time frame
Floorplans with off ices and interiors	Floor layout Offices for each department and individual Final location of meeting- and smokers rooms (within the limits of the masterplan) Off ice furniture and equipment	Interior partitions Local technical services Materials, colours and finishes	Professional assistance: The Interior Designer End users Department managers Project leader	3 months

6. Conclusions

In a strategic process for adaptable design, an important issue is to shift the designer's and client's perspective from short term realisation and profit to longer term goals. It is also important to develop a knowledge of the entire life cycle of the office building and the users' possible, future demands. The understanding of the building as a static product of the construction process, not intended or designed to change, is perhaps the most important obstacle for the design of adaptable buildings.

In the past, design of adaptable building has been more or less synonymous with adding in physical flexibility, such as modular partitions etc. We might argue that there is a lot to gain by focusing on other types of adaptability in the building, e.g. multifunctionality, robustness and extendibility. This is, however, not the main focus of this paper. The main objective is to highlight the importance of <non-physical>> strategies for adaptability. We have presented an example of how a layered decision and design process has been successfully implemented in a Norwegian renovation project. The strategic approach is what makes this example valuable for others to study.

The Decision Hierarchy is one strategy to ensure strategic, long term decisions as well as possibilities for change on a day-to-day basis. As in all design and decision making, awareness of the process and its dynamics, the actors and the information flow is vital in order to design adaptable office buildings.

7. References

- Blakstad, S. H., A. Christiansen, et al. (1997). Dagbladet hovedprosjekt, delrapport 3: Tilpasningsdyktighet i planleggingsprosess og kontorlosninger. Trondheim, Norway, SINTEF Bygg og miljøteknikk.
- Blakstad, S.H. (1997). Work productivity and adaptability in modem office buildings - a case study of Dagbladet. Conference proceedings IFMA/EuroFM 1997. STF22 S 97 55 1.
- Brand, S. (1994). How buildings learn. What happens after they're built. UK, Viking.
- Wigenstad, T. et al. (1997) FoU Dagbladet Hovedprosjekt. Delrapport 1. Fleksibilitet og lønnsomhet i tekniske installasjoner. STF22 A97561.

New classification system for easy identification of the content and use of standards by standards users

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Abstract
Starting from the ICS classification created by ISO, UNI (the Italian National Standards Body) together with DISET - Politecnico di Milano has developed, in a research funded by CNR (the Italian National Research Council), a new classification system incorporating a better "hierachizated" structure, from the general to the detail, that fits very well the computerized search of the existing standards as well as the classification of new EN standards for the building sector.
The new classification system is meant to ease the identification of the contents and the use of the technical standards- by all the operators of the building process, from commissioning to dismantlement/recycling, and to improve sustainable building practices.
The paper presents the new classification system in the version developed and validated for the UNI DATA BASE and that has been proposed by UNI as a basis for the revision of both the allocation of descriptors in the construction field of CEN and the ICS in the building sector of ISO.
Keywords: information classification system, building standards' data bank, sustainable building practices

1 Introduction

The new classification system and the data bank are the results of a five years research programme titled: "Completion and implementation of the Classification of National and European Technical Standards according to new criteria and descriptors - Prototype of a Standards' Data Bank in the field of application of the Construction Products EC Directive", funded by the CNR (the Italian National Research Council) Goal Oriented Building Project and developed by UNI (the Italian National Standards Body) together with DISET - Politecnico di Milano.

The research team was composed by: Pierangelo Boltri, Bruno Daniotti, Angelo Lucchini, Carlo Marucci, Roberto Morandi, Giuseppe Turchini, Mario Sanvito.

The main goal of the research was to ease and to improve the use of technical standards from the various building operators (investors, contractors, designers, users, etc.). This required the definition of a list of operators and the consequent detailed analysis of their needs, usual terminology and habits very useful to structure the Standards' Data Bank on the real needs arising from their professional work.

In other words the leading idea was to structure the Standards' Data Bank more on the needs of its users' than on those of the standardmakers.

As direct consequence of such choice a new information classification system had to be defined.

2 The new information classification system

The new information classification system was defined to allow the easy and quick search in the Standards' Data Bank of the information that matches specific users' needs.

The classification system was then structured into more "fields" each one representing a possible way of approaching or selecting the standards' information and therefore of defining a specific path or tree of searching.

The structuring of the classification system in separate fields allows the comparison in Boolean way of the results gatherable by different paths, to obtain the selection of information that better fits the user needs.

The classification fields are organized in two main groups: one for those concerning the identification of the standard, and the other for those regarding its technical contents.

In detail the first group includes the following classification fields:

1. *Standard title*
2. *Standardisation body:* UNI, CEN, ISO, etc.
3. *Standard code: e.g.* UNI 8270, IS0 140, etc.
4. *Dates:* of publication and revision;
5. *Standard rank:* regional, national, european, international;
6. *Standard character:* compulsory or agreed; draft, operating or in revision standard;
7 *Field of application:* use destination/s (see Table 1) to whom the standard has relevance.

The second group comprises these other classification fields:

1. *Object:* it indicates the part/s of the building the standard refers to.
   This field is hierarchicly structured from the most general and complex items concerning the: indoor environment, indoor spaces, building parts as a whole, outdoor environment, construction tools and facilities (see table 2) to the various categories of building components and technical equipments, down to the products' families (see table 3).

Code	Field of application
1	all buildings
2	houses
3	intermittently occupied buildings/ hotels
4	leisure/sport buildings
5	urban infrastructures
6	schools and universities
7	office buildings
8	commercial/shop buildings
9	industrial/production buildings
10	stock buildings
11	hospitals/sanitary premises
12	community buildings

Table 1. Codes and classification of the “field of application” field

Code	Object: general and complex items
1	Building indoor environment
2	Indoor space distribution
3	Building technological system
4	Building outdoor environment
5	Construction tools and facilities

Table 2. Codes and classification of the first level of the “object” field

Code	Object: categories of building components and technical equipments
3.1	*Subsystems:*
3.1.1	Foundations
3.1.2	Elevation structures
3.1.3	Connecting structure for stairs, lifts, ramps, etc.
3.1.4	Vertical envelope: external walls, windows, etc.
3.1.5	Upper horizontal envelope: roofs, skylights, etc.
3.1.6	Lower horizontal envelope
3.1.7	Ground horizontal envelope
3.1.8	Internal vertical partitions: internal walls, doors, etc.
3.1.9	Internal horizontal partitions: floors
3.1.10	External vertical partitions: fences, gates, parapets, etc.
3.1.11	External horizontal partitions: balconies, external ramps and stairs
3.1.12	Heating, ventilation and air-conditioning systems
3.1.13	Water supply systems
3.1.14	Drainage systems
3.1.15	Discharge plants for aeriform substances
3.1.16	Movement systems for waste materials
3.1.17	Gas supply systems
3.1.18	Electric equipments
3.1.19	Phone and data transmission installations
3.1.20	Lifting and transportation systems
3.1.21	Fire alarm installations
3.1.22	Anti-gas installations
3.1.23	Protection installations against electric discharges
3.1.24	Antitheft installations
3.1.25	Indoor furnitures and appliances
3.1.26	Outdoor equipments

3.2	*Components and products:*
3.2.1	Materials, semi-manufactured and for general use components
3.2.2	Protective paintings
3.2.3	Adhesive and sealing products
3.2.4	Joint elements
3.25	Thermal and acoustic insulating products
3.2.6	Waterproofing and vapour barrier products

Table 3. Codes and classification of the "object" second and third level

2. *Prevailing building material:* when relevant, it allows the identification or exclusion of some materials or products, it can be mentioned for completing the description of the object or used independently (see table 4).

Code	Prevailing building material
1	Ferrous metals
2	Non-ferrous metals
3	Clay
4	Ceramic
5	Cement, concrete, gypsum, mortar, etc.
6	Wood and derived materials
7	Bituminous materials
8	Rubber products
9	Plastics products
10	Glass and derived materials
11	Natural stones and derived materials
12	Textiles
13	Other generic categories such as composites, etc.

Table 4. "prevailing building material" field's codes and classification

3. *Agents/Phenomena:* they allow the identification of eventual relevant agents, actions, solicitations and effects (e.g. for test methods) (see table 5).

Code	Agents and phenomena
1	Acoustic
2	Atmospheric and pneumatic
3	Biological
4	Chemical
5	Mechanical
6	Electrical and magnetic
7	Hydraulic
8	Optical-luminous
9	Igneous
10	Radioactive
11	Thermodynamic

Table 5. Codes and classification of the "agents and phenomena" field

4. *Requirements:* it indicates the requirements the standard eventually refers to. The essential requirements defined by the EC directive on construction and bulding products are listed first and separately from other economical, functional and technical requirements (see table 6).

Code	Requirements
1	*Essential requirements [i]*
1.1	Mechanical resistance and stability
1.2	Fire safety
1.3	Hygiene, health and environment
1.4	Safety in use
1.5	Sound insulation
1.6	Energy saving and heat insulation
2	*Other requirements*
2.1	Economy, durability and reliability
2.2	Dimensional fruibility/accessibility
2.3	Aestethics
2.4	Building and management safety
2.5	Information management

Table 6. Codes and classification of the "requirements" field

5. *Items:* it is always applicable., it indicates the informative content of the standard (see table 7).

Code	Items
1	Terminology, classification, symbols
2	Requirements
3	Specifications
4	Laboratory test methods
5	Field test methods
6	Calculation methods
7	Codes of practice
8	Contractual technical aspects, qualification procedures and similar

Table 7. Codes and classification of the "items" field

The information classification system was definitively set up in the version nere presented only after numberous tests performed on a small prototype of Standards' data bank in which only about 200 standards where inputted. The contents of these standards were well known to the research team members.

In this phase many searches were successfully tested using different accesses to the data bank with reference to various needs of information, thus simulating the typical necessities and behaviour of more categories of building operators.

Once the ICS was validated the problem became the classification of all the standards and laws that had to be stored in the data bank.

To this goal a handbook explaining in easy terms and with the help of many examples the new ICS application was edited and given, after a detailed presentation, to every member of the technical secretariat of UNI together with the task of cataloguing all the standards related to their specific field of competence. After a few samples of standards' cataloguing, meetings were held to check and discuss the practical aspects of the new ICS application and the handbook effectiveness. Some small integrations of the handbook were recognized necessary. Once the handbook was updated all the standards given to each member of the UNI technical secretariat were successfully catalogued.

This job was done quickly and really well. It allowed the creation of the "UNI CNR building standards' data bank" in which all the classified standards were inputted.

For the future, to facilitate the input of the standards' classification directly by the staff of the technical secretariat or by the technical committees of UNI, digital input masks were prepared corresponding exactly to the paper cards used to classify the standards in the research here presented.

The classification operations will be integrated in the editorial process every standard from the very beginning to help the precise identification of its scope and contents according the new ICS here described.

3 The "UNI CNR building standards' data bank"

Since the 80's UNI and DISET Politecnico di Milano had already created two prototype data bases for the building standards' with simpler technologies: one on paper cards and one on diskette, both were really useful only to those users who having enough knowledge of the existing standards were able to search and select them only on the basis of their title and/or number.

Nevertheless, on the basis of the informatic prototype UNI has developped at the beginning of the 90's a standards' data base called "UNI edil", were *edil* stands for *building,* that has got quite a good success among some Italian building operators, some Public and Private bodies, Universities, Technical High Schools, etc.

It was therefore considered more useful and-convenient to incorporate, with the help of the UNI data elaboration office, the new classification system into the "UNI-edil" data base.

The final prototype of the "UNI CNR building standards' data bank" (see Figure 1) is on a CD-ROM in which the old and the new data bases coexist to ease the standards' searching and to maintain the original output of the complete standard in digital format at the same time.

Any data base user can search the standards using both the new classification system and the old generic search fields; in particular the new classification system allow the parallel searching in all the new fields (see figure 2).

Every search leads to a list of standards, each one with its number and title. The abstract and/or the full text and figures can than be obtained on the video and printed as well.

Besides the user may perform Boolean operations among the standards' lists selected in parallel through different classification fields, this to obtain the group of standards that fits his needs.

To facilitate the use of the new building standard's data bank a User's guide and an Help-on-line, both explicating the meaning of the terms used for the standards' classification and how to perform the standards' search, were also prepared.

5 Conclusions

The new information classification defined by UNI and DISET Politecnico di Milano allows the easy and quick search in the "UNI - CNR Standards' Data Bank" of the information that matches the specific needs of the various operators of the building sector. It has been successfully validated.

At the moment, World Wide Networks gives their users a lot of information which is not easy to access, because of its scattering in differently organised databases.

With a classification system like the one here presented it would be much easier for the building operators to find the information that suits them.

The new information classification system has therefore been proposed by UNI as a basis for the revision of both the allocation of descriptors in the construction field of CEN and the ICS in the building sector of ISO.

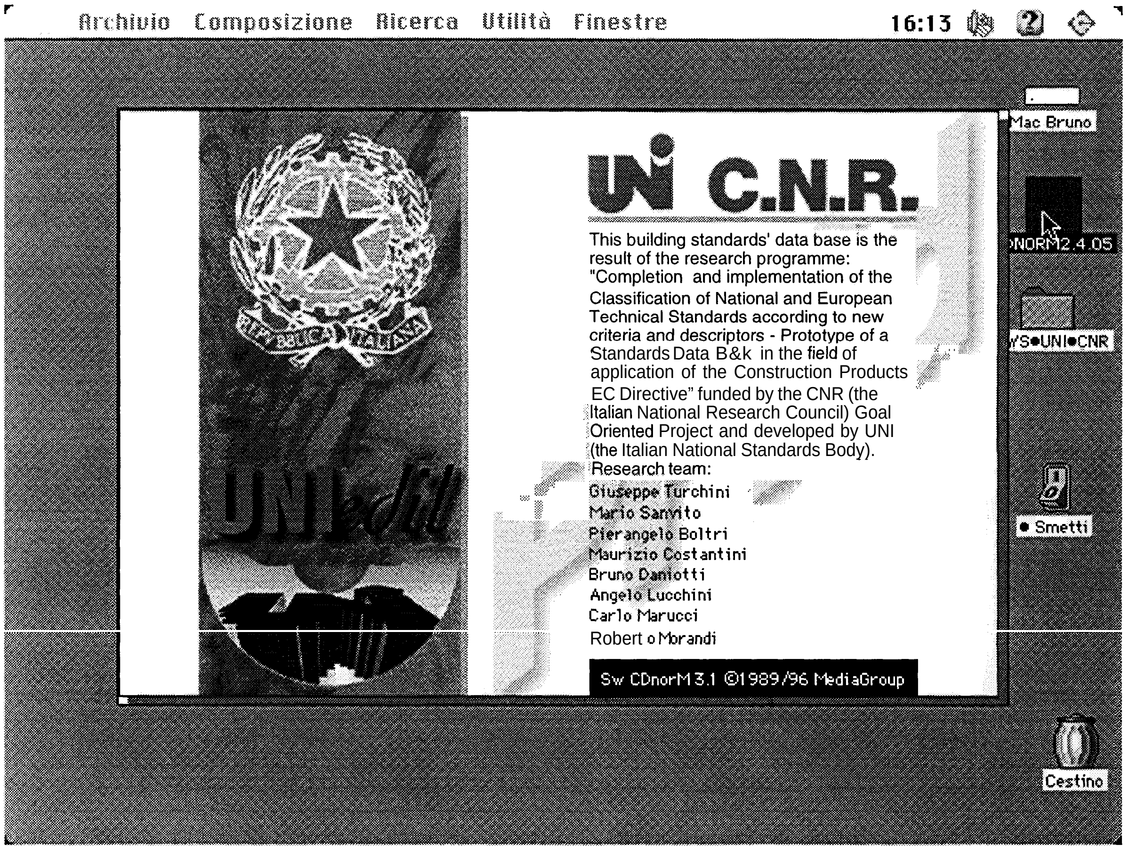

Figure 1. UNI-CNR Building Data Base

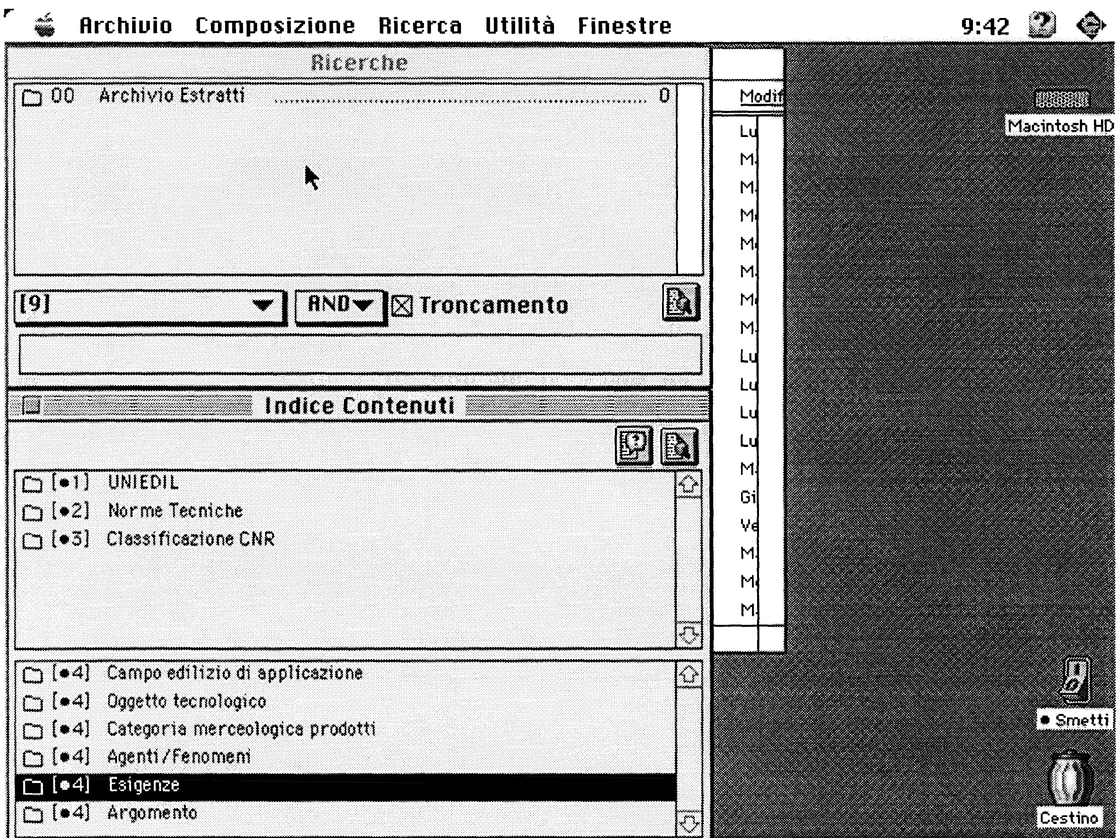

Fig. 2. UNI-CNR Building Data Base chief search menu.

Legend of figure 2		
Campo edilizio di applicazione	–	*Field of application*
Oggetto tecnologico	–	*Object (components and equipments)*
Categoria merceologica prodotti	–	*Prevailing building material*
Agenti/fenomeni	=	*Agents/phenomena*
Esigenze	=	*Requirements*
Argomento	=	*Items*

6 References

1 The Council of the European Communities (1988) Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (89/106/EEC). Annex 1. Essential Requirements. Official Journal of the European Communities, No. L 40/12, 11.2.1989.

2 Comunicazione della Commissione concernente i documenti interpretativi della Direttiva 89/106/ CEE del Consiglio, n° 94/C62/01.

3 CNR - Progetto Finalizzato Edilizia - Sottoprogetto "Informatizzazione delle procedure" - Ricerca "Razionalizzazione del sistema normativo nazionale come fase del processo edilizio" (Responsabile: G. Turchini - ricercatori: P. Boltri, B. Daniotti, A. Lucchini, M. Sanvito) - Relazione finale del primo anno della ricerca 1989 - 90

4 Idem - Relazione finale del secondo anno della ricerca 1990 - 9 1

5 Idem - Relazione finale del terzo anno della ricerca 1991 - 92

6 Idem - Relazione finale del quarto anno della ricerca 1993 - 94

7 Idem - Relazione finale del quinto anno della ricerca (conclusiva) 1994 - 95

Promoting BEQUEST: Building Environmental Quality Evaluation for Sustainability through Time.

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Abstract

The broad aim of the BEQUEST Network is to create a forum for concerted pan-European research, training and practical action in assessing the quality of the urban environment in order to identify the basis for a common understanding and implementation of sustainable urban development. The network has been funded for three years under the European Union Environment and Climate RTD programme, and is due to start operation in April 1998. This paper gives an account of the key features of the network and its modus of operation. We are developing an internet supported system for working and communicating that will address the role and responsibilities of industrial, commercial, and all other societal actors involved in the development and use of the built environment across the scale from individual buildings to whole cities, in EU. member states.

At the core of the network are the 14 partners from research institutions across Europe who will drive the programme forward by a series of workshops at intervals of a few months, and continuous use of a dedicated intranet. The results of our work will be tested by the societal actors who are associates of BEQUEST, on an extranet of partners and associates. The extranet will allow for formative assessment of BEQUEST products with immediate feedback.

In the first year of the programme we will identify and analyse existing sustainability blueprints, and current approaches to implementation. Through this process, we will build up a common understanding, and recognition of cultural and environmental diversity. In the second year we will produce:

1. An analysis and classification of assessment methods
2. A protocol for sustainable development
3. A decision matrix to promote understanding of the protocol.
4. A directory of sustainability advisors to promote implementation of the protocol.

The remainder for the project will be concerned with testing and disseminating the protocol and its “tool kit” firstly with our associates and then with all other interested parties in Europe responsible for shaping the built environment. We will also set up Internet and other structures to promote continuity of this initiative.

Keywords: Built, City, Environment, Extranet, Internet, Intranet, Sustainability, Urban.

1 Introduction

The BEQUEST Network arose out of the conference, "Environmental Impact Evaluation of Buildings and Cities", held in Florence in September, 1995 [1]. The main objective of this group is to lay the foundations of a common EU. understanding of sustainable urban development through a multi-disciplinary network of representatives of all actors involved in the provision, use and maintenance of the built environment. An integrated approach to built environment quality assessment is to be developed which will help to reduce the environmental uncertainty facing decision makers in the development and infrastructure industries. For this major European project the network is to be expanded from the present size of fifty members in 10 countries to create a broad international, interactive community composed of a very wide range of disciplines from both the demand and supply sides of the development, infrastructure and construction industries, in order to assess the built environment at a range of scales, from building component design through to strategic city planning, across a range of cultures and regions. The context of research project is shown in Figure 1. The groups represented in this figure are derived from the work of ATEQUE [2]

2 Background

The difficulties in reconciling the demands of modern commerce and transport with the desire to provide a good quality environment have long been recognised. The associated congestion, pollution, noise, deterioration of streets, public places and architectural heritage and general loss of amenity experienced is seen as a very difficult collective problem requiring broad understanding and multi--disciplinary action. [3]

The problem is compounded by other factors:

* the increasing urbanisation of humankind - two thirds of Europeans now live in urban areas [4],
* the longevity of buildings and city infrastructure - 60 to 100 years is not unusual for individual buildings,
* the very large quantity of resources which existing cities contain and which are consumed annually to continuously develop, maintain and use them.(In the UK it has been estimated that the construction industry uses about 6 tonnes of building materials annually for every member of the population [5]).

If all these factors are considered together then the built environment sector presents one of the biggest challenges for society, both in terms of the development of a collective aspiration for better quality, more sustainable patterns of living and the time it will take put these ideas into effect [6].

A key issue is the scale of impact on a spectrum extending from the individual to the global level embracing buildings, urban districts and cities. It is clear that some definitions of sustainable urban environments seek a better environmental and economic balance between the city and its hinterland, whilst others look towards greater autonomy of urban communities. Increasing the density of urban areas as a means of intensifying land use and transportation efficiency is being examined, but this approach is also questioned in terms of the functionality of the cities and the quality of environment that might result [7, 8].

At the district/city scale local authorities have established various local objectives under Agenda 21 [9]. The usual response is to identify local "indicators" which will be used to benchmark the current environmental performance of a community and against which future improvements can be measured. A wide range of alternative indicators are being used by differing local authorities and these do not always coincide with those suggested nationally [10] which will mean differing objectives and standards, not just across national boundaries, but even between neighbouring local authorities. In this context it is important to note that Agenda 21 proposals constitute entirely voluntary action. In the meantime major city or infrastructure projects must continue to undergo environmental impact analysis in line with EU Directives [11]. These regulations are interpreted in national planning control guidelines which will, at best, ameliorate the negative environmental consequences of larger scale projects.

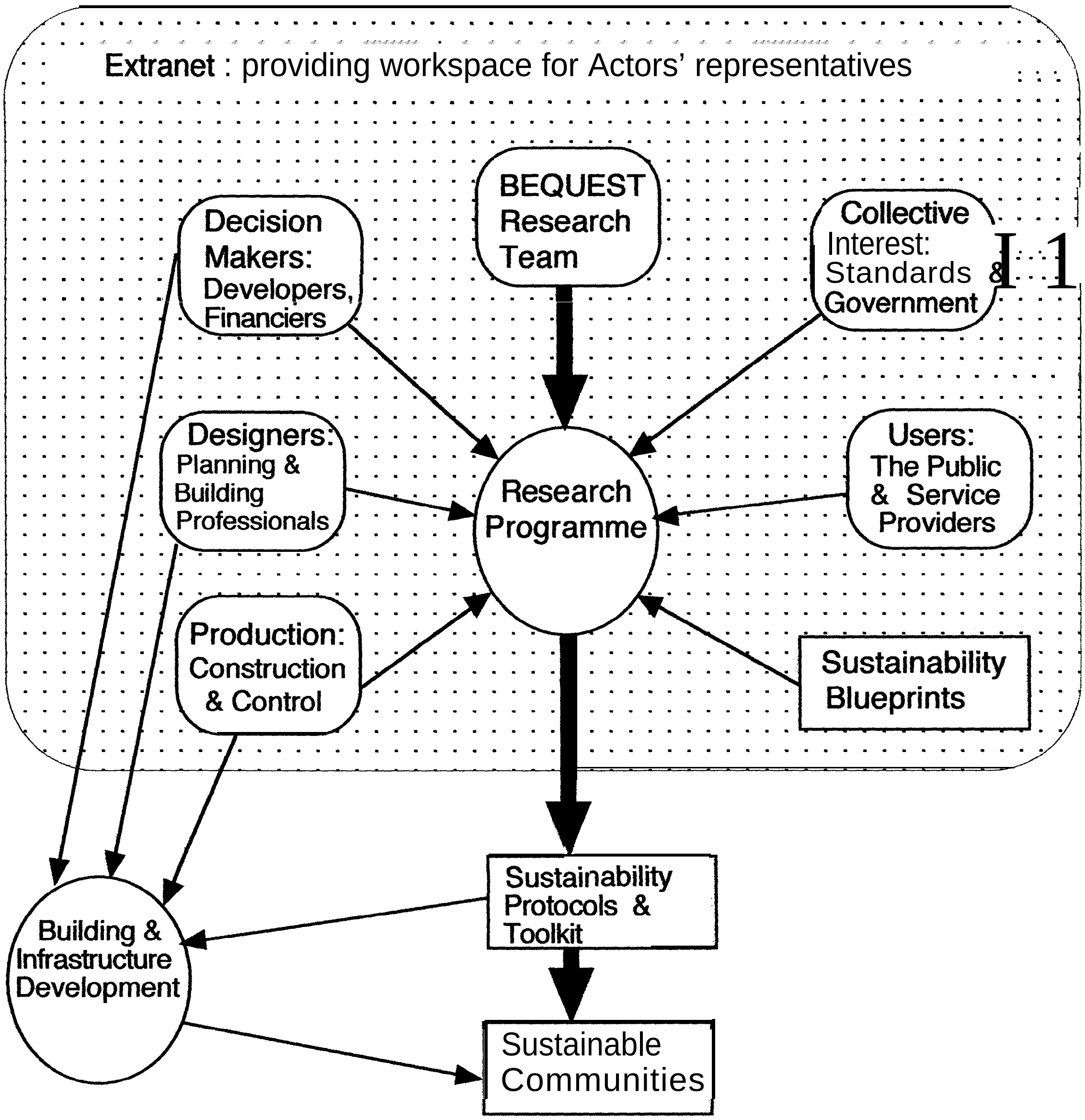


Figure 1 Context of the research showing influences and primary outcomes

At the building scale regulations in the majority of Northern European Countries are aimed at ensuring good standards of energy efficiency in new buildings. Increasing numbers of new buildings may undergo some form of broader environmental assessment at design stage, e.g. BREEAM [12] and BEPAC [13]. Other systems are under development in a number of countries, e.g. Sweden and Germany, and internationally through the Green Building Challenge [14]. However, as with Agenda 21, these systems or methods are not regulatory-requirements and so standards and application is very variable across building types and across different nations.

Many of these environmental assessment techniques were conceived with a view to reducing the environmental impact of building and urban development, rather than pursuing the broader goal of sustainable cities. At present each of these areas of assessment have developed and continue to operate discretely and as such it is far from clear that individual actions are actually contributing to real improvements in the sustainability of towns and cities. How then should the professionals within the construction and development industry recognise and respond to these features and criteria? What has emerged is a very clear need for greater dialogue between all societal actors at each level of the building-city spectrum, together with better sustainable development assessment "tools", in order to converge towards a more common understanding of what constitutes a good quality, sustainable urban environment. This is the reason for existence of the BEQUEST Network and its primary objective is to develop a taxonomy or "road map" through this difficult territory.

3 Research method

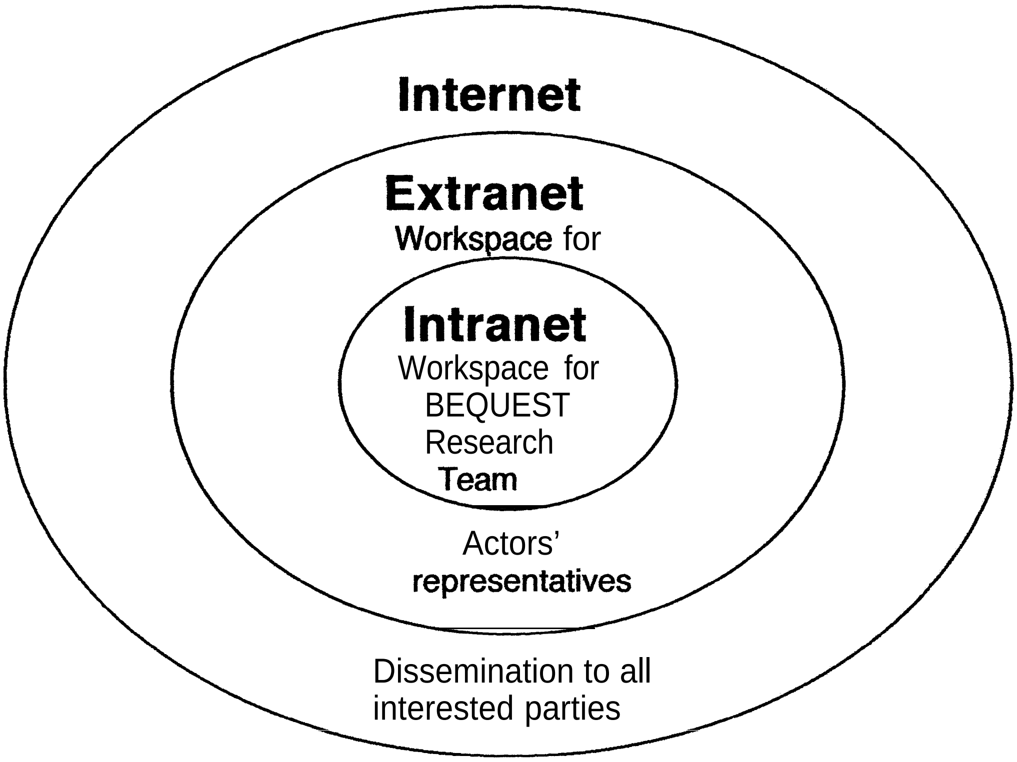
In EU parlance the BEQUEST project is a "Concerted Action", i.e. it attempts to bring together current research thinking and practice. Therefore throughout all three years of the project consultation and negotiation with a wide range of actors from both the demand and supply side of the property and infrastructure sectors across the EU will take place via a consultative network described as the BEQUEST Extranet, see Figure 2. This process will tap the highly diverse knowledge and expertise of a wide range of environmental researchers, professionals, infrastructure providers and managers in order to build a consensus definition - or, where this is not possible, to clearly recognise and understand where the differences lie between member states, levels of action, interest groups and professions. Mature deliberation, debate and evolution are key elements of the whole project and so an iterative learning cycle of workshops and report back to the Extranet members is planned. The members of the consortium, to be known as the Intranet, see Figure 2, will act as mentors and facilitators of this process. Interim findings are to be made available through an electronic news letter.

In the second and third years of the project finished documents will be inter linked, and logical pathways through the documents will be provided by a decision matrix. By the end of the project this will create a decision support tool-kit which will make use of, and be interlinked to, existing Internet sites concerned with all aspects of sustainability and sustainable development.

4 BEQUEST objectives

The members of the network have identified five main objectives which taken together provide a detailed Agenda for all professional actors to consider in the context of sustainable urban development:

* development of a common language & understanding of sustainability between all the parties engaged in the built environment.
* better understanding and the development of more appropriate environmental quality assessment methodologies for sustainability
* development of a common integrated framework for assessment
* identification of environmental quality standards and the dissemination of best practice.
* to implement these ideas in order to catalyse change.



Intranet. In the initial stages of the project an intranet will be set up to facilitate immediate communication between members of the research team. The intranet will be a discussion forum and will also hold documents in the process of production; it will thus be a means of collaborative working. Access will be limited to researchers, who will be able to air embryonic or partially formed ideas within a closed community.'

Extranet. The extranet will be a forum for Actors' representatives. They will also use the extranet to test the products of research in conjunction with the BEQUEST research team.

Internet. When the tool kit is fully developed and tested it will be published on the Internet.

Figure 2. Communications and workspaces

5. Assessment methods and models

An essential paradox of a sustainable society is the conflicting requirements of sustaining the local and global environment whilst at the same time providing for the flows of production and consumption needed to maintain a good quality of life for humankind and, simultaneously, taking account of issues such as social equity and bio-diversity. The project is examining a number of blueprints and concepts that have emerged which attempt to answer all or some part of this challenging agenda, such as "Natural Step", the "Service Economy", PICABUE, "Ecological Footprints" and Natural Capital.

In the pursuit of sustainable urban development, what tools and models do we need and how will we use them? In order to completely represent the complex interactions that represent the city are we faced with a problem akin to "modelling the universe" ? How can we, at the same time, remain modest? A wide range of environmental quality and performance assessment methods are available, such as EIA, BREEAM, BEPAC, Eco-Points, Multi-Criteria Analysis, etc. New techniques are emerging from current EU programmes such as SPARTACUS, ULYSSES, SUSTEE, etc. Can these techniques be integrated into an effective multi-modal framework that addresses all aspects of sustainability and how is this to be achieved?

We have defined the essential characteristics of this framework as developed from the working of CIB TG8 [15]:

* object orientated, i.e., capable of describing the city and its sub-elements
* functional, i.e., capable of assisting decision makers to make trade-offs
* transparent, i.e., capable of identifying data buried in an aggregated score (poor aggregation destroys information)
* value sensitive, i.e., capable of expressing values from a range of individual perspectives.
* integrative, i.e., capable of assisting professional co-ordination

To be able to handle complexity we need to identify, from the long list of parameters that can and should be considered in an assessment, those which are the primary effects. As identified earlier, the degree of difficulty of meeting different assessment requirements could be reduced or eliminated by transforming or amalgamating some parameters into fewer, more general indicators. Conventionally the main candidates for this are money and energy. Identification of reliable indicators is a problem in itself - there is a risk of false or incorrect understanding, like measuring the speed of the car by the tachometer. A process of gradual research and evolution will be necessary in order to increase our confidence in the selected indicators and provide better understanding of which indicators we can safely use in which circumstances and in which locations a process that will take longer than the lifetime of the BEQUEST project.

Central to the identification of indicators is the issue of the sphere of investigation - the spatial dimension. Different factors in assessment - energy flows, commuting travel distances, pollution, food production, building raw materials etc. - each have a separate area of influence with its own boundary, that can be traced from a particular community. In the affluent countries food is clearly sourced world wide. It &increasingly obvious that building materials are also glob& commodities, and this is becoming- common between both the affluent and less affluent countries. The selected domain has major implications. The problems of international agreement over these issues is a major stumbling block to the development of life cycle analysis tools for buildings and construction products. We need these agreements if we are to have effective cooperation from manufacturers, who argue that there must be a standard system - a level playing field so that, for example, manufacturing does not move to locations where there are lower pollution control requirements.

6 Facilitating change

A city is a living entity. The environmental impact is the sum of that resulting from all the individual actions of the population. Thus, to continue the motoring analogy, trying to facilitate change is akin to tying to mend the car whilst driving along. We have to carry all the citizens with us - they must wish to change their behaviour and aspirations if we are to have any hope of moving towards sustainable patterns of living and working. Thus it is crucial to developing effective means of public participation. The key issues are:

* How are unexpressed interests of stakeholders taken into account?
* How is access to information provided to all stakeholders?
* Are they able to participate, do they have the appropriate language and understanding?

Answers to these questions are vital if we are to empower individuals to change there own lifestyle.

In market economies, participative mechanisms are unlikely to create change unaided due to the strong influence of capital in directing and determining the nature of much urban development. BEQUEST's aim is to establish methods and procedures which individuals and groups (see Figure 1) can readily appreciate and use, both in terms of environmental quality assessment and in terms of participative procurement systems. The project is designed to involve a significant number of the “doers and shakers” and to use their comments and views to develop really workable environmental assessment and procurement tools.

7 Conclusions

The membership of BEQUEST represents a significant cross section of the professional actors involved in the urban development process and so the spread of views and lack of consensus on what constitutes sustainability is very worrying in terms of developing concerted, coherent action towards Sustainable Urban Development, SUD, in practice. Clearly this requires all actors to begin to address the broader problem, to "think about things they have not seen as part of the problem". Essentially designers and developers need to accept the need for wider participation in development decision making. Financiers and developers and their design teams should seek much greater resource efficiency in all aspects of building and infrastructure procurement. Policy-makers need to recognise the broad principles involved and begin to provide a clearer lead, a clearer vision of what SUD is and the types of life style that r-night accompany it. They also need to provide a better regulatory and fiscal background that will clearly facilitate appropriate change. All need techniques which will adequately value the quality of the built environment as well as the social, resource and natural capital contained in our existing communities.

A key conclusion to be drawn from the work of the BEQUEST Network to date is that in the pursuit of greater sustainability in buildings and cities, simple technical and economic analyses will prove to be inadequate, without better multi-modal assessment techniques and more thorough social and political integration. Thus society as a whole has to seek answers to the following questions:

* What can and should we be aiming-for in SUD?
* What targets should we set ourselves and which are the right sustainability indicators in any individual situation?
* What are the best environmental assessment methods to use where, to identify indicators and measure progress?
* How can these indicators and methods be integrated to reduce uncertainty in decision making?
* How can the results of a more integrated analysis be made more meaningful to all actors so that they can more clearly understand the options and thus effectively participate in the development process?

Answers to all of these questions are necessary for us, i.e. both BEQUEST and society in general, to begin to have a common language so that we can recognise whether affluent countries are really moving towards more sustainable patterns of living and working, rather than just thinking (or wishing) that they were there!

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References

1. Brandon, Bentivegna & Lombardi (Eds) *Environmental Impact Evaluation of Buildings and Cities for Sustainability*, Proceedings of International Workshop, Florence, Sept. 1995, E&FN Spon, London, 1997
2. ATEQUE ,1994, *Identification of Actors Concerned with Environmental Quality of Buildings*, Technical Document No. 1., Paris, December 1994
3. Commission of the European Communities, 1992, *Towards Sustainability: A European Community Programme of Policy and Action in relation to the Environment and Sustainable Development*, COM (92)23 final, CEC, Brussels.

4. European Environment Agency, 1994, *Europe's Environment - The Dobris Assessment,* EEA, Copenhagen, Denmark.
5. Building Research Establishment, 1996, *Buildings and Sustainable Development,* Information Sheet Al, BRE, Garston, Watford, UK
6. Curwell, S. & Cooper, I., 1996, *BEQUEST Network Workshop: summary of proceedings,* Department of Surveying, University of Salford, England.
7. Breheny, M. *(Ed.),* 1992, *Sustainable Development & Urban Form,* Pion, London, UK.
8. Jenks, M., Burton, E & Williams, K.(Eds.), 1996, *The Compact City: a Sustainable Urban Form?,* E & FN Spon, London, UK.
9. United Nations Association, 1995, *Towards local sustainability: a review of current activity on Local Agenda* 21 *in the* UK, UNA-UK, Sustainable Development Unit, and the Community Development Foundation, London, England.
10. Rotheroe, C et al, 1997 "Do the indicators of sustainable development produced by the UK Government and indicators developed within various local Agenda 21 initiatives have common characteristics from which core indicators can be developed?' Proceedings of the 1997 International Sustainable Development Research Conference, Manchester, pp 238-245, ERP Environment, UK.
11. Commission of the European Communities, 1985, Council Directive of 27 Jume 1985 on the assessment of the effects of certain public and private projects on the environment. *Official Journal of the European Communities* C175: 40-9, 5 July 1985.
12. Building Research Establishment, *1990, Building Research Establishment Environmental Assessment Method: BREEAM Version 1/90 - An environmental assessmentfor new office designs,* BRE, Garston, Watford. UK
13. Cole, R.J. and Rousseau, D. and Theaker, I., 1993, *BEPAC: Building Environmental Performance Assessment Criteria, Version 1: Office Buildings,* The BEPAC Foundation, Vancouver, Canada.
14. Cole, R.J. and Larson, *N.,* 1997, *Green Building Challenge Assessment Manual, Vols 1 &* 2, CANMET , Natural Resources Canada, Ottawa, Canada
15. Cole, R.J. (Ed.) 1996, *Linking and Prioritizing Environmental Criteria, proceedings of the CIB TG 8 International Research Workshop,* Toronto, Canada, 15-16th November, 1995

Bibliography

Cooper, I., 1996, Environmental assessment methods for use at the building and city scales: constructing bridges or identifying common ground? in Brandon, P. et al (eds.), *Environmental evaluation of the built environment for sustainability,* conference proceedings, Florence, Italy, 13-15 September, 1995.

Cooper, I. & Curwell, S., 1997, The Implications of Sustainability for the Environmental Assessment of Buildings and the Construction Industry, Proceedings of Workshop "Buildings and the Environment in Eastern Europe, CIB Task Group 8, Warsaw, Poland , October, 1996.

Eclipse Research Consultants, 1996, Mapping commitment to sustainable development: a self-assessment technique for policy-makers and practitioners, ERC, Cambridge, England.

European Union Expert Group on the Urban Environment, 1994, *European Sustainable Cities: First Report of the of the EU. Expert Group on the Urban Sustainable Cities Project,* XI/822/94 -EN, Brussels.

Mitchell, G., May, A., and McDonald, A., 1995, PICABUE: a methodological framework for the development of indicators of sustainable development., *International Journal of Sustainable Development and World Ecology,* Vol. 2, pp. 104-123.

United Nations Conference on Environment and Development, 1992, *The Earth Summit* '92, Regency Press, London.

Sustainable development in construction

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Abstract
A review of concepts of sustainable development and its assessment are given in this paper and some critical comments made. Considering the magnitude of the impact of the construction industry on the environment, a considerable improvement in efficiency and effectiveness of the construction process is necessary to help to restore the ecological balance. Further development of life cycle assessment techniques and social and economic aspects of sustainability will play an increasingly important role.
Keywords: Sustainability, sustainable construction, sustainability criteria, indicators.

1 Introduction

This paper attempts to review current thoughts on sustainable construction particularly with regard to the main elements of sustainable construction and sustainability criteria and indicators. It will also review environmental assessment methods currently in use and attempt to develop an agenda for future research in sustainable construction.

There is growing evidence that the earth's ability to sustain life as it has been known for thousands of years has been seriously eroded, particularly since the Industrial Revolution, and if unchecked, will result in an irreversible degradation of the planet, its ecosystems, resources and ultimately quality of life of its inhabitants in the not so distant future. Modern forms of human existence, associated with rapid economic development, have contributed to an over-exploitation of renewable natural resources such as land and forests, and the exhaustion of non-renewable resources such as minerals and fossil fuels. The generation of CO_2 emissions well in excess of the natural carbon storage capacity, ozone layer depletion, the contamination of air, water and land through pollutants and the weakening of the whole ecosystem are also apparent. Depending on regional and often political issues, the importance of such phenomena may not always be recognised. Often insufficient or inconclusive data is available on environmental problems.

While most countries have in the past 10 years committed themselves to work actively towards improving the environment, the challenge in the future will be to mobilise every individual and every business to embrace change through a range of activities. These may be as simple as recycling household wastes and products, energy and water conservation, rejection of disposable in preference to recycled products, and the demand for reduced packaging of products. At the regional and national level, more wide ranging changes may be expected such as lower emissions, use of renewable sources of energy, better land management and the reduction of population growth.

The research methodology adopted for this study is based on literature review only. An extensive search was carried out and relevant journal articles, conference papers and books summarised. Because of the restriction on the length of this paper, no literature review section is included.

2 Sustainable construction

2.1 Definitions

According to DuBose et al [1], "***sustainability offers a way of interacting with our world which reconciles the ubiquitous human desire for a high quality of life with the realities of our global context. It calls for unique solutions for improving our welfare that do not come at the cost of degrading the environment or impinging on the well-being of other people*".**

Sustainable development or ecologically sustainable development was defined by WCED [2] as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The term 'development' includes activities across different industry sectors. As the impact of the construction industry on the environment rates as one of the highest among all the industries, a close scrutiny of the construction industry is necessary to minimise its impact on the environment, hence the emergence of the term 'sustainable construction'. A clear definition of 'sustainable construction' as a subset of sustainable development will serve as a starting point for any such scrutiny. In the context of this discussion, the word 'construction' implies a process which starts well before the actual on-site building activity commences and extends to post site-building activities such as commissioning and asset management. In fact, it covers an entire project development life cycle.

The term sustainable construction was originally proposed to describe the responsibility of the construction industry in attaining sustainability, see Hill and Bowen [3]. They have singled out four attributes of sustainability – social, economic, biophysical and technical – to advance understanding of the concept of sustainable construction. Kibert [4] sees sustainable construction as creating a healthy built environment using resource-efficient, ecologically based principles. According to Lawson [5] and Wyatt [6], sustainable construction includes 'cradle to grave' appraisal, which includes managing the serviceability of a building during its lifetime and eventual deconstruction and recycling of resources to reduce the waste stream usually associated with demolition. Bourdeau et al [7] defined sustainable construction as the creation and responsible maintenance of a healthy built environment based on resource efficient and ecological principles.

2.2 Impact of construction on environment

Construction industry is commonly one of the largest industries in both developing and developed countries in terms of investment, employment and contribution to GDP. Consequently, the impact of the construction industry on the environment is expected to be considerable particularly as far as the loss of soil and agricultural land, the loss of forests and wildlands, air pollution, and the loss of non-renewable energy sources and minerals are concerned [8].

According to Levin [9] buildings' contribution to total environmental burden ranges between 12-42% of the eight major environmental stressor categories: use of raw materials (30%), energy (42%), water (25%) and land (12%), and pollution emission such as atmospheric emissions (40%), water effluents (20%), solid waste (25%) and other releases (13%). Buildings and building construction services account up to 66% of total UK energy consumption [10]. A similar level of energy consumption in the USA (54%) was quoted by Bonini and Hanna [11]. They further reported that the US residential sector is the highest consuming sector. Cooper and Curwell [12] estimated that in the UK the construction industry uses about 6 tonnes of building materials annually for every member of the population.

The above figures clearly support the notion that the construction industry imposes considerable loading on the environment and impacts severely on practically every environmental issue affecting sustainability. The challenge for the construction industry is to re-engineer its entire process in order to significantly reduce its impact on the environment.

2.3 The key principles of sustainable construction

The above definitions of sustainable construction are all framed towards creating a healthy built environment through resource efficient and ecologically sound processes, preservation of ecosystems and maintenance of natural balance between development and carrying capacity of this planet. The key principles upon which the above definitions have been phrased can be summarised into the main principles of sustainable construction. A range of models detailing principles of sustainable construction will now be briefly reviewed.

Hill and Bowen [3] aggregated the principles of sustainable construction into four pillars – social, economic, biophysical, and technical. These are supplemented with a set of over-arching, process-oriented principles. ***"These process-oriented principles suggest approaches to be followed in deciding the emphasis to be given to each of the four pillars os sustainability, and each associated principle, in a particular situation".***

Palmer et al [13] classified the principles underlying sustainable development as futurity, environment, public participation and equity. These were adopted as the principles of sustainable urban development by BEQUEST [12]. More definitions of principles of sustainability can be found in DuBose and Pearce [1], Graham [14], Wolley [15].

3 Sustainability criteria and indicators in construction

Performance criteria and indicators in sustainable construction are needed to assess the performance of a building/facility and measure its impact on the environment. They need to be comprehensive to address specific environmental issues/problems. These are commonly identified as population growth, availability and use of natural resources such as land, water and forests, depletion of non-renewable resources such as mineral reserves and fossil fuels, urbanisation, pollution, geopolitical problems, habitat destruction/deterioration (biodiversity loss), global warming, stratospheric ozone depletion, soil erosion, acid deposition, wastes, indoor environment.

A considerable effort will be required to translate the requirements for sustainable construction into specific, technical performance criteria for buildings, components, systems and materials. Cole and Larsson [16] defined performance criteria as the basic building blocks which formulate the specific characteristics of the building/facility that will be assessed. Performance indicators are then specific units of measurement that will be used to describe the performance criteria in both quantitative non-quantitative forms. They are parameters of values that provide information about a phenomenon. They gauge progress towards sustainability in a simplified and readily understandable way. However, they need to encompass the relevant environmental impact and other sustainability aspects, be verifiable and measurable, be mutually independent of each other, and be comparable to a reference level [17].

A hierarchy of performance criteria and indicators for specific environmental issues/problems in a matrix format is possible to develop, see DuBose and Pearce [1], Levin [9], Beetstra [17], Chatagnon and Nibel [18], Guy and Kibert [19].

4 A brief review of environmental assessment methods

The first generation of environmental development controls in Australia was known as an environmental impact statement of a new development. It was to show the impact of the proposed development over its lifecycle on the surrounding environment and how the development satisfied the local urban planning requirements. These controls were regional in nature and focused on issues such as traffic flow, noise, size and height of the development, pollution, landscape, rogue reflection, disposal of surface water, etc. Without any performance benchmarks, environmental impact statements were judged subjectively within the context of prevailing social, economic and political climate.

In the last decade or so, a wide range of environmental classification or building rating systems based on life cycle assessment (LCA) emerged in response to commitments to sustainable development by a number of developed countries. Among the best known systems are BREEAM (UK), BRE Office Tool Kit (UK), Home Energy Rating (UK), BREDEM (UK), Waster/Environmental Data Sheet (Europe), European Eco-labelling (Europe), SIB (Switzerland), BauBioDataBank (Germany), Ecocerto (Italy), EcoLab (Netherlands), BMES Index (Australia), Athena (Canada), BEPAC (Canada), LEED (US). A brief review of the above systems can be found in Cole and Larsson [16] and Wolley [15]. Beetstra [17] and Gay et al [20] criticised LCA, claiming that many environmental aspects have been left out and that LCA method is not capable of weighing different sustainable criteria and assess trade-offs among various environmental objectives. The method is said to be too complex when all building materials and components are considered and thus unusable unless various criteria and indicators are aggregated.

A growing need for a more rigorous and systematic assessment of projects has provided an impetus for the development of many new assessment methods. A brief review of some such new methods under development will now be given.

Beetstra [17] reports on the development of BEDS - Building-related Environmental Decision Support, a new integral assessment method in Netherlands. The method composed of a limited set of objectives, and quantitative and verifiable indicators, can be used in all phases of a project development cycle. In total eight indicators are used, three of which are site oriented (use up of space; accessibility; green balance), three are building-oriented (water balance; energy balance, HBF influences), and two are aimed at building elements (material use, reuse). Indicators will measure outcomes in numerical values between 0-100% with 100% being the maximum yet technically realised level.

Levin [9] outlines the development of SEABEP - Systematic Evaluation and Assessment of Building Environmental Performance model. "*SEABEP addresses* the *need for comprehensive performance evaluation and assessment based on life cycle assessment, comparative risk assessment, and industrial ecology*". It assesses the contribution of buildings to the total environmental burden, weighs various environmental problems on a global scale and on a local or project scale and establishes targets based on defined sustainability criteria.

Chatagnon and Nibel [18] describe a methodology for the development of a model in the form of a matrix for environmental assessment in the design phase of a project. It targets continuous assessment of the environmental quality of a project at different design stages. The evaluation model calculates the environmental effects due to the sources, and expresses them according to assessment criteria. The proposed procedure is iterative and allows each project to be assessed from the environmental quality point of view.

A different approach to assessing sustainability of projects is described by Gay et at [20]. This approach attempts to develop a sustainability index appropriate for assessment of buildings. The index is determined by *"expressing environmental impacts of a building in terms of external costs which represent either measurable or calculable costs of direct impacts such as health injuries, death of the forest, etc., or the costs of preventing these"*. The fact that the final result can be expressed as a monetary sum is being seen as an advantage. When added to the conventional construction cost, an easy comparison between different alternatives will be possible.

DuBose and Pearce [1] advocate the use of The Natural Step (TNS) method for environmental assessment of buildings that was developed by Robert [21]. The proposed methodology consists of interpreting specific TNS system conditions and finding building-specific indicators for each of the system conditions. The authors concede that while comprehensive, this approach is rather complex.

Cole and Larsson [16] present an overview of GBC 98 – 'The Green Building Challenge' project, which is being developed in Canada. The aim is to develop an environmental assessment system and establish internationally comparable benchmarks for building performance. The system will measure Basic Performance such as functionality, maintainability and economic performance, Green Performance such as energy use, land use, materials use, airborne emissions, etc., and Process Performance to evaluate whether certain protocols have been specified. The proposed system will be able to address global and regional issues, and will also make it possible to measure both potential and actual performance.

5 Future research agenda

It may be useful to consider this in two overlapping parts based on the type of building technology to which it relates.

Conventional building technology, based on bulky, common, cheap materials has led to initiatives in waste reduction, recycling, regulatory control and conventional life cycle assessment based on a building life of 50 to 100 years. Sustainability is largely seen as a question of balance between what can be extracted with minimal environmental impact and demand. It is assumed that these can be readily agreed and quantified and the relevant sums done. Design for deconstruction (DFD) to facilitate recycling [22] is based on reducing the quantity of virgin raw materials needed to be extracted and used or in reducing the need for landfill disposal.

New building technology, based on the use of fewer materials in a more sophisticated or 'clever' manner (Less is More) points in a somewhat different direction. Assessment of sustainability may focus on what is covered in assessment schemes rather than attempting to standardise and agree a fixed methodology. Life cycle assessment may be based on a much wider range of building lifetimes, from very short (accompanied by total recycling/reuse/renewability) to very long (where environmental impacts are 'written off' over the long life of the building). The focus of attention may shift to relatively small quantities of key resources or materials which play an important role in modem sustainable building. These might include the alloying agents in steel rather than iron ore and limestone, rare metals such as titanium and indium which may come from very environmentally sensitive areas (eg. beach sands) or because they are rare, generate an inordinate amount of waste in their production. These rare elements may play a critical role in the development of ecologically sustainable building and DFD will be based on the recovery of small quantities of critically important materials. They may become politically strategic further complicating issues of equity.

The issues of equity in the social and socio-economic aspects of sustainability, both within and between countries, will become more critical as populations continue to increase and demand higher material standards of living.

6 Conclusions

The ability of this planet to maintain an environmental equilibrium has been disturbed, perhaps irreversibly. Population expansion and the corresponding increase in consumption on one hand and the reduction in the carbon storage capacity through deforestation on the other pose the most critical threat. The construction industry is the major contributor to the environmental loading on the earth and needs to respond to by substantially improving efficiency and effectiveness of in its entire production process. However, with an inevitable increase in population and demand for buildings and infrastructure services, even a dramatic improvement in environmental management of the construction industry is unlikely to offset an overall rise in the environmental loading caused by the increased level of building activity. If the scientists are correct in warning that the carrying capacity of the earth has already been disturbed, then the major challenge will be to minimise the rate of consumption increase and match it with a corresponding improvement in environmental efficiency and effectiveness associated with human activities.

How this is achieved will differ according to circumstances. The development of life cycle assessment techniques and their role in the assessment of sustainable construction will continue to be crucial. As building technologies develop further the key elements of sustainability may change and researchers need to be aware of such developments.

Social and economic aspects of sustainability need to be further developed.

7 References

1. DuBose, J.R. and Pearce, A.R. (1997) The Natural Step as an assessment tool for the built environment. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 595-602.
2. WCED (1987) *Our common future.* World Commission on Environment and Development, New York, Oxford Univ. Press.
3. Hill, R.C. and Bowen, P.A. (1997) Sustainable construction: principles and a framework. *Construction Management and Economics,* Vol. 15, pp. 223-39.
4. Kibert, C. J. (1994) Final session of *First International Conference of CIB TG16 on Sustainable Construction,* Tampa, Florida, November.
5. Lawson, W. R. (1992) Capital energy costs of building and the recycling of building materials. *Proceedings of Construction Beyond* 2000, Espoo, Finland.
6. Wyatt, D.P. (1994) Recycling and serviceability: the twin approach to securing sustainable construction. *Proceedings First International Conference of CIB TGI* 6 *on Sustainable Construction,* Tampa, Florida, November, pp. 69-78.
7. Bourdeau, L., Halliday, S., Huovila, P. and Richter, C. (1997) Sustainable development and the future of construction. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 497-504.
8. Spence, R. and Mulligan, H. (1995) Sustainable development and the construction industry. *Habitat International*, Vol. 19, No. 3, pp. 279-92.

9. Levin, H. (1997) Systematic evaluation and assessment of building environmental performance (ASEABEP). *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 3-10.
10. Vale, R. and Vale, B. (1991) *Towards a green architecture.* RIBA Publications, London.
11. Bonini, C.D. and Hanna, R. (1997) Integration of historic preservation and green architecture. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 221-28.
12. Cooper, I. and Cur-well, S. (1997) BEQUEST - Building Environmental Quality Evaluation for Sustainability through Time. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 515-23.
13. Palmer, J., Cooper, I. and van der Vorst, R. (1996) Mapping out fuzzy buzzwords – who sits where on sustainability and sustainable development. *Proceedings* 1996 *International Sustainable Development Research Conference,* Manchester Conference Centre, UK, March, pp. 181-88.
14. Graham, P. (1997) Assessing the sustainability of construction and development activity: an overview. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB* ,Vol. 2, Paris, June, pp. 647-56.
15. Woolley, T. (1997) The Green Building Digest – experience of providing information to construction professionals. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 1, Paris, June, pp. 207-14.
16. Cole, R.J. and Larsson, N. (1997) Green Building Challenge 98 (GBC98). *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 1, Paris, June, pp. 19-29.
17. Beetstra, F. (1997) Beyond LCA: building related environmental decisions. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 565-74.
18. Chatagnon, N. and Nibel, S. (1997) Environmental assessment method adapted to the iterative process of building design: presentation of the methodology. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 57-66.
19. Guy, G.B. and Kibert, C.J. (1997) Developing indicators of sustainability: US Experience. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 549-56.
20. Gay, J.B., deFreitas, J.H. Ospelt, C, Rittmeyer, P. and Sindayigaya, 0. (1997) Toward a sustainability indicator for buildings. *Proceedings Second International Conference on Buildings and the Environment, CSTB and CIB,* Vol. 2, Paris, June, pp. 575-84.
21. Robert, K.H. (1991) Educating the nation: The Natural Step. *In Context,* Vol. 28, Spring, pp. 10-15.
22. Lawson, W.R. (1994) Design for deconstruction. *Proceedings of Buildings and the Environment Conference.,* BRE., Garston., UK.

SUSTAINABILITY IN MANAGEMENT AND ORGANISATION: THE KEY ISSUES?

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Abstract

This paper provides an introduction to some of the key issues relating to the context of sustainability. It argue's for a more holistic approach to sustainability built around a consensus of an agreed definition and a philosophical framework to allow a meaningful discussion to take place, leading to improved decision making. It recognises that at this emerging stage of the topic, even these matters are research issues and that in parallel with this debate it is important that progress at the sub-problem level must continue. The paper points out the issues as a means of providing context for many of the papers in these proceedings.

Keywords: evaluation methods, framework, management, philosophy, research, sustainability.

Introduction

The purpose of this short paper is to provide a context to the research issues relating to sustainability from the perspective of management and organisation. This is a difficult issue to address. By its nature 'management' is engaged with intervention and yet it is often the intervention of human management and organisation in the past, which has led to an environment which many believe is unsustainable. This paradox can be explained, it is often said, by the absence of the 'right' criteria to take the long term view, the absence of knowledge concerning the manner in which man-made products and human settlements behave, and the prioritization of economic performance above all else. No doubt this is true, but even today the remnants of the debate between those who wish to conserve all the earth's natural resources at all costs, and those who believe a technological 'fix' can be developed, still rages on. Within these polarised stances is a whole spectrum of view which attempts to find a middle way responding to new crises, new knowledge and new developments in an ad-hoc manner. The advocates of this more pragmatic approach attempt to feel their way through this uncertain and opaque world by dealing with the issues as they arise. Nevertheless the short-comings of such an approach are evident as the response to one problem often exacerbates another. For this reason there has been a call, which has grown in momentum over the past decade, for a more holistic approach, engaging all aspects of the various systems which impact on the environment and endeavouring to assess the interaction between them. Out of this view has grown the concept of sustainability.

This concept is still poorly defined, but it seems to contain certain features which make it distinct. It is about endurance rather than conservation, although conservation, particularly of non-renewable resources, plays a large part. It is holistic and attempts to avoid the trap of reductionist approaches, but has yet to establish a framework within which there is a shared vision to which all can contribute. It implies both self-control and discipline within society which may well require sacrifice now in order to allow future generations not to be disadvantaged. It also recognises change as an essential ingredient of universal systems, including evolution within the bio-sphere and the impact of knowledge in human development, but suggests that a measure of intervention can be beneficial. These features will be seen to be embracing of some of the most complex issues known to man and it would be unwise to move down the path of setting specific goals with high expectations. It is likely to be an exploration, a journey, a revealing, rather than a conclusion which we can expect as we progress.

Within this overview of sustainability as a concept the built environment represents a subset. It is however a significant player in its own right, and also has a significant impact on the world in general. Looking in, it engages the most basic needs of man in terms of accommodation, comfort and social organisation. Looking out, it impacts on the quality of the natural environment, the quantity of non-renewable resources and the services needed to support human gatherings in any form. At its most prevalent, within the urban context, it permeates the whole fabric of human existence and extends into the eco-systems upon which all living species depend. No consideration of sustainability can avoid consideration of the structures human beings have developed to accommodate themselves.

Within the context of this symposium 'management and organisation' applied to sustainability has a major, difficult and maybe impossible task. If the aim of management is 'to bring about or contrive' or 'to direct or conduct the affairs' of something (as suggested by Websters Comprehensive Dictionary) then the discipline has a problem. At this moment it is not clear exactly what it is to 'bring about' and in most cases it does not have the authority 'to direct or conduct the affairs' of all the factors which would lead to a sustainable built environment. For obvious reasons the complexity of a built development means that the management task is divided. Those that exercise control encompass individuals, governments, local authorities, regulatory bodies, companies, suppliers and so forth, and these relate to public perceptions, media, global agendas and many more beside. What is it realistic to expect within this subject domain? Even within the more limited field of the environment this matter has been identified. Wolfgang Sachs (1993) wrote this:-

"Once, environmentalists called for new public virtues, now they call rather for better managerial strategies. Once, they advocated more democracy and local self-reliance, now they tend to support the global empowerment of governments, corporations and science. Once, they strove for cultural diversity, now they see little choice, but to push for a worldwide rationalisation of life-styles. Indeed, as ecological issues have moved to the top of the agenda of international politics, environmentalism appears in many cases to have lost the spirit of contention,, limiting itself to the provision of survival strategies for the powers that be. As a result, in recent years a discourse on global ecology has developed that is largely devoid of any consideration of power relations, cultural authenticity and moral choice, instead it rather promotes the aspirations of a rising eco-cracy to manage nature and regulate people worldwide. Ironically, a movement which once invited people to humility has produced experts who succumb to the temptations of hubris".

There is a default to 'regulation' to manage the complexity and a view that 'the expert knows best'. It is no wonder therefore that those of us attending this symposium relating to sustainability of the built environment proceed with some caution into the contribution that management and organisation can make to creating sustainable environments. Within the global picture what intervention can we make that aids rather than hinders this goal? If we are to manage in a sustainable way then there are many aspects upon which we must be clear. These can be summarised as follows:-

- A clear definition and understanding of what we mean by sustainability must be sought
- A philosophy which can lead to an understanding of the relationships between the different complex factors contributing to sustainability must be shared in a public consensus. This aspect cannot be exclusive to the construction industry and its clients alone.
- A robust classification system which structures the problem must be established in such a way that the complex inter-relationships can be modelled must to aid communication, understanding and the growth of knowledge
- A set of measures which allows progress to be calibrated and which is related to the aspects above must also be developed. Otherwise how do we know what progress has been achieved?
- A management framework must be developed which allows for planning, design, construction, monitoring and feedback on sustainability as an integral part of the development and occupation cycle. Without this framework the sustainability agenda is sterile and inoperable
- A protocol for decision making must be established within the above framework which challenges those involved in the decision process to respond to sustainability in a positive way. It must engage, where appropriate, the regulatory bodies and the

judiciary to enforce the public consensus

Definition

If there is one subject which still attracts debate, then it is the question of 'How do you define sustainability?'. This is surprising since the term is in common parlance and literally thousands of people across the world are studying it as a subject. Nevertheless what is included or excluded creates tension and vigorous discussion. David Pearce in 'Blue Print for a Green Economy' (Pearce D.W. et al) provides several definitions for 'sustainable development' and others have done the same. Perhaps the most widely accepted definition is that of Brundtland (WCED 1987).

.... '*sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*'.

The problem with this definition is that 'needs' is left undefined - does it extend beyond survival and is so, by how much?

The Brundtland Report (WCED 1987) went further in trying to establish meaning

'*In essence, sustainable development is a process of change in which exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance current and future potential to meet human needs and aspiration*'.

Again the question of 'needs' arises, but also the question of 'harmony'. From whose perspective is 'need' and 'harmony' to be judged. These are not trivial questions and inevitably they lead to prolonged debate.

In an interesting paper Beckerman (1994) queried whether 'sustainable development' was a useful concept. He asks whether it is a technical condition or a moral injunction. He states that

"*The result of the fusion of technical characteristics with moral injunctions is that the distinction between positive proposition about the threat to the continuation of any development path and normative propositions concerning the optimality of any particular pattern of development is hopelessly blurred. Instead, a sustainable development path should be defined simply as one that can be sustained over some specified time period, and whether or not 'ought' to be followed is another matter. It should be treated, in other words, as a purely technical concept - not that this necessarily makes it easy to define operationally*".

This splitting of the two issues is interesting but it must surely be recognised that the moral imperative has been a major driving force behind the consideration of sustainability. Without it the discipline required in behaviour now, in order to address the needs of future generations, may be difficult to achieve. In addition it is far too restricting to just consider the 'technical characteristics' as it is often the political, social and economic domains which dominate whether something is sustainable or not. These factors are often driven by considerations arising from moral judgements. A simple technical 'fix' will not necessarily result in a more sustainable built environment. A much richer definition is required which encompasses all the factors and helps decision makers determine what 'needs' and 'harmony' mean from current and future perspectives. It may be that the 'Brundtland' definition can remain the objective and we further define it in terms of a philosophy and a framework.

Philosophy and Classification

The problem with sustainability (as opposed to some aspects of conservation for example) is that it engages the whole of human existence and the complexity of inter-relationships which make up this universe. 'No man is an island' can also be applied to every facet of nature and the systems we have created to tame and control it. The inter-relationship between systems, and between people and systems, means that the impacts are far reaching and their complexity suggests it is difficult to predict. Who knows whether the butterfly flapping its wings in Malaysia will eventually impact on weather patterns in the USA? The change in weather pattern may then impact on human behaviour and their life styles and hence create a new set of patterns eventually impacting on the life of the butterfly. This is of course an exaggeration, but the point remains that the myriads of combinations of 'happenings' result in change which it is difficult to predict.

How we view this world affects the manner in which we prioritise our behaviour and the way in which we make decisions. A philosophy which places human beings at the top of the agenda would be different to one which is not species specific. It is impossible to avoid facing this question if we are to take a holistic view. It is also one that has been a major debate among human beings for centuries, dividing East and West through religion and behaviour. Managers almost by definition are making decisions which are based on a set of assumptions about the world and the particular culture in which they live. It would be practically impossible to get all human beings to sign up to a common view even if it could be expressed. So what can be achieved? We could set out a framework which at least makes the assumptions upon which we act explicit. This framework would not be a discrete set of classes but would allow continuity, systems, classification, calibration and networking within a nested arrangement expressing a holistic view of the world to be captured.

This is an ambiguous target and the author has been working with Lombardi (1997) to at least find a starting point for such a holistic approach. For the moment we have settled on the work of the Dutch philosopher Dooyeweerd and his 'Philosophy of the Cosmos' as an attractive way forward. The main contribution of Dooyeweerd is that his theory is explicitly trans-disciplinary, yet provides integration between disciplines and systems; it considers different levels of information, nesting all aspects of reality in an ordered manner, yet provides structure and continuity; and it recognises the importance of multi-person action across different time scales albeit with a specifically western (and Christian) view. Consisting of fifteen modalities spanning the numerical to the credal it attempts to explain the world and its activities in an ordered and structured way. The paper by Lombardi in these proceedings outlines some of the key issues.

Without such a structure it is extremely difficult to approach sustainability in an ordered and systematic way. It would also be difficult to handle the complexity of different systems and place them in context or enable a dialogue with a common vocabulary to be established for all the many participants engaged in decision making related to sustainability. It would be dangerous to promote a single view or perspective of a problem which is so complex. Nevertheless some rationale is required. As we move to a better understanding, no doubt several philosophical frameworks will emerge. Philosophical approaches are sometimes seen as ethereal, but in fact their importance cannot be over-emphasized when seeking solutions within complex value-laden domains such as the built environment. The language which leads to classification and structure of such theories help to untangle the complexity and enable a sharing of the concepts.

Measures

If a structure based on a consensus around a philosophical framework can be developed then the calibration of the criteria found within the structure is the next step. Without some form of measure or assessment progress cannot be charted. Once again it is the complexity which creates many of the problems. How do we cope with the balancing of all the different factors which lead to the 'harmony' which in turn contributes to a sustainable built environment. Techniques, such as Cost-Benefit Analysis, which attempt to reduce all assessments to a common measure, eg. money, are inadequate in such a problem domain. Even techniques such as multi-criteria analysis, where ranking of criteria can be an output, only provide a step towards structuring the problem. Bentivegna (1997) in an excellent critique of environmental evaluation methods concludes by saying:-

"..... evaluation cannot be but a tool for argument within the comprehensive collective decision process relating to the environment because its conceptual framework is controversial, its methods are valid only within a narrow validity field, and its outcomes represent only a share of the interests in the game. Therefore the task is limited to clarifying ideas and allowing a better comparison among alternatives than ordinay language can do, so enriching the debate'!

It is important to realise that evaluation of any sort represents a particular view (which may or may not shared by many people) even when the evaluation is numerical. Collecting together many different evaluations brings together many viewpoints and the tools to integrate them into a single composite expression or, worse still, numerical measure are simply not available. It is unlikely that any one of the contributing perspectives could sign up to the composite in any meaningful way. Not only would the values and priorities be different between contributors, but they may well be in a conflict eg. economic activity may be essential to sustain the community which requires a built environment but this activity may also be in conflict with the need to protect non-renewable resources.

Nevertheless the viewpoints are expressed and articulated (however inadequately) and this in itself is a useful starting point from which improvement can be sought. If we can identify the components that contribute to sustainability then over time, we can seek appropriate measures. For the moment a 'profile' of performance, as far as we understand it with our current knowledge, is probably the best we can hope for. The various Environmental Impact Analyses for buildings tend to be of this sort and perhaps 'sustainabilty' requires a similar framework.

The role of evaluation changes therefore, from the difficult task of giving an improbable objective judgement, to one of representing different points of view, useful for reaching a 'good' decision and, importantly, developing a learning process. If we can stand back from the implied assumption that we have complete and full knowledge at any point in time and realise that we are creating a reference point which we can use an a datum to build, monitor and compare, then the concept of sustainability has a chance of remaining a feature of assessment for many years to come. By its very nature the evaluation is usually long term and we know that our knowledge is extremely unstable in terms of human activity. To expect an evaluation or even 'measure' to remain stable would be unrealistic. We must realise that change is inevitable and our systems must accommodate this. This leads us into the need for a management framework and protocol for implementation.

Management and Decision Protocols

It follows from the previous discussion that in order to create a sustainable environment, some level of intervention is required to seek the goals which are defined for a building or an urban environment. Indeed the papers in this symposium address largely these issues. It is most unlikely that leaving matters to the 'market' or 'survival of the fittest' will create the development which will comply with our requirement not to compromise the ability of the future generations to meet their own needs. Engagement of the needs of sustainability with the decision making process of development is therefore vital if it is to form part of the routine assessment of design and construction. Some of the requirements for sustainability will be found in legislation (which will demand a satisfying of certain standards) but not all. To achieve improvement we need a careful and rigorous modelling of process which allows us to identify when and in what form intervention is necessary. However even this can be inadequate, for while it is relatively easy to model activities arising from design in a systematic way, the process of design and creativity, at least in its conceptual stage is often a closed book. Most of the research into design suggests that the architect is wrestling in his mind with complex scenarios at various levels of detail and with several parallel lines of thought (Lawson 1993). The impact visually, spatially and technically (in the choice of services, materials, texture etc) will be significant to the contribution that building or neighbourhood makes to the overall environment and its sustainable characteristics. At the very least the 'intervention' at this stage must be through the education of the designer and his access to knowledge at the appropriate time in his thought process. It must be part of his or her philosophy on design. The closest we have come to such an input was the call in the 1960's to include the 3 L's concept into design decision making ie long life, loose fit, low energy. This concept is now being revisited.

The key to both education and knowledge is the feedback mechanisms and here there is a problem. Sustainability is about the long term and even with a willingness to gather information in occupation it is difficult to capture, analyse and feedback useful data to designers at the present time. To widen the data capture to all the stakeholders contributing to sustainability, is probably impractical. The pay-off is doubtful and the interest of both designers and clients in capturing such information appears to have a relatively short time span. Some partial information on performance could be obtained on the more technical aspects by remote sensing, but it is likely that it is the social/political/economic context which will have the major impact. Any analysis of these matters is almost certainly to be subjective and value laden. It may be that the discipline of facilities management has a major role to play in the future to study, observe, analyse and report on sustainability issues, but these are likely to be insights rather than hard data. They will be retrospective views and subject to the same biases identified in all recorders of history!

Construction management is likely to play a more peripheral role than design when considering sustainability, assuming that good design has been implemented through good quality construction processes. The focus for construction must be on improved quality which makes it natural and/or desirable to sustain a building or group of buildings. This 'quality' will encompass performance, energy, waste, emissions, longevity and all the aspects of current and future 'needs'.

The problems for those engaged in the management of development can therefore be summed up by asking firstly "How do I make a decision on sustainability where we are forecasting far into the future, we have no hard data and our evaluation techniques are inadequate?". One approach is that we need to create a dialogue leading to a consensus between those with expert knowledge and those who benefit from the built environment. This should take place within a framework which we all understand. It is a similar point to that made by Bentivegna (1997) quoted previously.

The next question is "When should this dialogue take place?". Here a consensus around a protocol would be beneficial. Some of the work on process protocols in the production industries could be useful here, Cooper (1998) has endeavoured to define such protocols for construction with the identification of 'soft' and 'hard' gates in proceeding through a development. It may be that sustainability issues should be placed alongside the more conventional development activities for consideration and forced into the agenda at each 'hard' gate. [The point at which the process cannot continue unless there is an agreed consensus or permission eg. planning given for the next stage to proceed]. In some cases compliance with statutory regulations will force the issue, in others it may be the demand of regulatory authority or client.

Finally there is a need for feedback mechanisms which provide useful and meaningful knowledge to both the designer and the owner/tenant of the building or, in the case of a neighbourhood, the local authority. Ideally this should be a continuation of the dialogue of the actors/participants/experts commenced at the planning and design stages.

Conclusion

The concepts expressed in this introduction will be familiar to all those engaged in the decision making process. The differences with regard to sustainability compared with other dimensions of the built environment management problem are primarily

- the even longer term perspective required on what is already a long term asset
- the wider social, political and economic context over this extended time period impinging on the evaluation of sustainability
- the greater number of actors, participants and experts engaged in the dialogue affecting the decision
- the lack of a framework in which that dialogue can take place and the difficulty of managing the discussion to ensure a proper balance between the competing objectives
- the absence of feedback mechanisms which can be relevant to informed decision making
- the weakness of evaluation tools to distil and prioritise criteria for effective decision making

At the 'building' level these issues are difficult to address, but they become far more of a problem within the urban context where the interaction between people, their social environment and their accommodation engages so much of the knowledge we know about the human world.

These proceedings contain papers which, in general, address various parts of the problem. They largely provide a way forward for decision making at the sub-problem level. It is hoped that this introduction has set these issues into the wider context and encouraged a holistic perspective on sustainability both at the individual building level and the urban contact. The subject is still in its embryonic stage and it will be interesting to see how it will emerge and evolve over the years ahead. It is most unlikely that it will disappear, but the degree of commitment with which it is addressed will reveal much about the seriousness with which we address it and the maturity of the research community to derive suitable models for the aid of all of us engaged in the development process.

References

1. Sachs W. (1993). **Global Ecology, A New Arena of Political Conflict,** Zed books, London, introduction page i).

2. Pearce D.W. et al (1989). **Blueprint for a Green Economy. Introduction,** Ecronscan, London.

3. WCED (The Brundtland Report) (1987) **Our Common Future.** Oxford University Press, P43

4. Beckerman W (1994). **Sustainable Development : Is it a Useful Concept?** Environmental Values. Autumn 1994, P 101

5. Lombardi P and Brandon P.S. (1997). **Towards a multi-modal framework for evaluating the built environment quality in sustainability planning,** in Evaluation of the Built Environment for Sustainability, (Editors Brandon P S, Lombardi P.L., Bentivegna V) E&FN Spon, PP 6-21.

6. Bentivegna V (1997). **Limitations in Environmental Evaluations,** in Evaluation of the Built Environment for Sustainability. (Editors Brandon P.S., Lombardi P.L., Bentivegna V). E&FN Spon, pp 25-38

7. Lawson B (1993). **Parallel lines of Thought,** Languages of Design. Elsevier Science Publishers, Vol 1, pp 321-33 1.

8. Cooper R et al (1998). **Development of a Generic Design and Construction Process,** PDT Conference, Building Research Institute, Garston, Watford, UK.

Horizon 2020: Design-Build

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Abstract
This paper focuses on Design-Build as a procurement strategy and attempts to outline the stimulants and impediments to its adoption as a dominant building procurement mode.

Previous research has identified procurement as a matching function between key actors on the demand side and those on the supply side. The relationships among these actors are subject to changes in the prevailing world view. In outlining the futures of the building process in North America, earlier research by the authors has identified shifts in critical paradigms which hold significant power for the evolution of the building process, in general and of the procurement strategies, in particular. A model previously developed by the authors is further elaborated to depict relationships that arise in the Design-Build mode. The dynamics of these relations are then analyzed using the critical paradigms and appropriate qualitative data. The qualitative data regarding trends in Design-Build is drawn from business, trade, professional and academic literature, as well as from field research.

The ensuing interdependence of the relationships among the actors in the procurement system offers a gauge of the dynamic complexity that underlies the Design-Build mode and affords a view for assessing its potential as a strategy of choice in the future.
Keywords: Building Procurement; Design-Build; System Dynamics; Models; Single-Point Responsibility; Stable Dynamic Networks.

1 Introduction

The construction industry is a powerful engine that contributes a significant force which drives the North American economy. In terms of GDP both in Canada and the United States, construction output is in the range of 13 to 16 %. To appreciate the relative magnitude of this figure, it is worth contrasting it to the output of the automotive industry in the United States which is approximately 3.5%. However, the construction industry and its subset, the building industry, while often used by statisticians and economists as indicators of the state of economy, are not as often the subject of organization and management studies at the enterprise level; rather research attention is focused at the project level or industry segment level. Yet the success or failure of the project often depends largely on the organizational forms of the participating firms, collectively ***and*** individually.

The organizational design of firms in the building industry has been dictated by a multitude of dominant and often contradictory factors. The building industry, characterized by Davidson [1] as a multi-industry, is a mature industry that has been subject to diverse traditions many of which have ultimately found their way to legislation. Thus, for example, architects and engineers are required to be licensed by professional regulatory bodies under the authority of provincial or state government. The general and specialty contractors are required to hold some form of license, insurance bonding: and/or union certification. While these requirements may vary from one jurisdiction to another, some form of control is exercised over the enterprise every where and this control is enforced by a variety of mechanisms including the process of building permits, administered by local authorities: Bidding requirements are another example of legislated tradition in some jurisdictions.

Technological progress and legislated tradition have not kept a pace, and the ensuing time lag has resulted in the creation of many artificial structural constraints and often costly devices to-overcome such constraints. The intense technical reauirements of the project have resulted in 'techno-polarities' that create a narrow focus of concern, resulting in the almost total exclusion of due attention to and appreci ation for business and management issues. In the midst of such apparent organizational disarray, it is understandable that there is a strong desire to embrace methods and techniques that seem to hold promise particularly if they seem to solve problems that are frequently encountered in the present situation. However one should be careful not to introduce new devils in an effort to get rid of the old ones.

The fragmentation of the building industry has given rise to the perception (i) that the building industry is something of an aberration when compared to the manufacturing process and (ii) that this 'anomaly' could perhaps be remedied if somehow the building process could be made to fit the mold of the manufacturing model. However, the building process appears idiosyncratic not so much as a result of anomalies to be eliminated but because of the unique requirements of the product this industry is called upon to supply with the requisite efficiency and competitiveness for the given environment [2]. The complexity of the building process is perhaps unparalleled by most other industrial processes – a situation that the building industry has learnt to cope with, despite the "apparent organizational disarray" we have referred to above.

A major impediment in exploiting the advantage offered by this situation is the inward view espoused by the building industry and the fact that perceptions and opinions it holds of itself may not accurately reflect current environmental demands and opportunities. Understanding the mechanics of the structural coupling of the participants and the strategies they employ, based on the prevailing organizational forms, holds the key to the effective deployment of innovative procurement strategies. However it appears that the developments surrounding Design-Build may be viewed by many as the catalyst for desired change, often to the exclusion of other approaches.

Nevertheless, the trend towards Design-Build does not by itself constitute an indicator of future success and long-term sustainability. Indeed we maintain that Design-Build is not the panacea that it is purported to be, and that the problems inherent in the design-build process far outweigh any advantages that may arise [3]. This perspective will be outlined as we answer the pertinent questions and provide a retrospective view of Design-Build. Broader environmental influences need to be surveyed if one wishes to understand the dynamics of reinforcing forces acting on these trends as well as the balancing forces most likely introduced by other factors.

2 Research Scope

This is the third in a series of articles on 'futures' of the building industry in North America [4, 5]. The previous articles focused on fundamental questions about procurement and the building process to the horizon of 2020. This article addresses specific questions about the future of a particular procurement strategy, Design-Build – again to the horizon of 2020.

The previous works followed accepted 'futures' methodological approaches about potential developments in the next twenty-five year horizon, as applied to the building industry; that approach is followed in this work as well. To summarize, the approach of Tait [6] combined with the application of General Systems Theory yields the holistic approach required for futures study, as discussed by Levy [7] and Senge [8].

3 The Building Industry and its Environment: A Paradigm Review

A model of the building industry and its regulating cycles, as influenced by the environment, was described by Katsanis and Davidson [4]. This model confirmed the view that the building industry is a system within a larger system and that the building industry is therefore subject to the prevailing forces in Society and will be under pressure to change as Society changes. Design-Build is representative of one such cycle occurring in the building industry, and as will be shown, is subject to the changes and regulating cycles of other future trends.

3.1 First Paradigm: Business Process Re-engineering (BPR)

BPR is a process defined by Hammer and Champy [9] as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements on critical, contemporary measures of performance, such as cost, quality, service and speed". Its application to the construction industry is considered in a proposed framework for research by Betts and Wood-Harper [10], who argue that the philosophy of BPR is akin to encouraging innovation and establishing learning organizations; it would suit a project-oriented industry, where the scenario described by Hammer and Champy [9] for "virtual teams for specific assignments" fits well with the multi-disciplinary design and construction practices of the building process.

3.2 Second Paradigm: Partnering

In the last few years, partnering has emerged as an alternative way of carrying out projects in the construction industry, in response to concerns about poor quality, low productivity and costly litigation, all of which can be traced (at least in part) to the adversarial relations between the key actors in the building process.

3.3 Third Paradigm: Specialization and Integration

Winch [11], in his examination of construction firms and construction projects, arrives at the conclusion that "in spite of the alleged benefits of hierarchy [i.e., of-integration] there has been little or no shift towards hierarchy with the [...] construction industry". Eccles [12] sees the relations between the quasifirms as a situation where "[all] parties can benefit from the somewhat idiosyncratic investment of learning to work together".

Indications also exist to support the view that current technologies and market attitudes favor extreme specialization and the formation of single-person firms. Bröchner [13] uses industry statistics that point to the growth of market share for such single-person firms. The project-centered nature of the building process is very conducive to this kind of arrangements which have been observed and recognized in other industries; they have been called 'Rolodex'* agencies or firms and they are not uncommon in other industries where specialists are involved in carrying out tasks on a project-by-project basis [14].

It also stands to reason that in order to exploit the efficiencies afforded by specialization, it is necessary to have access to skilled manpower, both at the organization and at the project

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* Rolodex is the trade mark of a rotating desk-top address file. The name: 'Rolodex organization' is derived from the fact that it relies mainly on a pool of resources to be assembled as the project needs require; it has no basic staff and is run by one or few specialists who lean on modern management techniques to make this kind of organization work.

levels. While unemployment is rising, the demand for manpower skilled in specific tasks is likely to rise until new and relatively stable patterns of demand result in the creation of new trades or disciplines.

3.4 Fourth Paradigm: Networks and Information Technology *(IT)*

Friedman [15] identifies a strong need for systems that transcend current organizational boundaries and allow the kinds of interaction that are now possible through computer-based communications systems. The technological feasibility of these systems already makes it possible to establish a new mode of organization, namely: the network. According to Best [16], networks of organizations are networks of lateral and horizontal interlinkages among firms, and they are the emerging antithesis of the old model of the large hierarchical firm. Such organizations are lean, agile, flatter organizations and are well suited to a project-based environment such as that of the building industry.New technologies have made possible the adoption of more disaggregated, distributed and flexible production arrangements, as well as of new ways for firms to organize their internal operations and to establish their ties with the firms with which they transact [17].

4 Design Build 2020: Questions to be Asked

Using the methodology outlined earlier, based on morphological analysis, and drawing from the lessons to be learnt from the current paradigms, we can posit answers to the following questions: 1) What is the assessment of Design-Build as a future strategy of choice for the building industry? 2) What are the stimulants to Design-Build as a procurement strategy?, and 3) What are the impediments to the adoption of Design-Build as the dominant procurement mode?

Clearly, Design-Build is not new; however this begs the question as to why it has not secured a more dominant place among available procurement strategies.

5 Design-Build: A Brief Retrospective

Design-Build as a method for procuring a built facility is not a novel idea. While in the last several years, Design-Build figures prominently among procurement strategies, its distinguishing feature, viz., that of 'single point responsibility' conjures up the practices of the master builder going back to Roman times [18]. It is the demarcation of professional domains of architects and engineers and those of the various trades that took place in the 19th Century that lead to what we call today the traditional approach of Design-Bid-Build [19]. While Design-Build was once prevalent primarily in large industrial projects [20], its use gained popularity in the U.S. in the 80s as governments opted for this delivery method in an effort to simplify the issue of who is responsible for what, i.e., for any claims that may arise in the course of the project.

In recent years, Design-Build has become a major strategic option and it has sparked keen interest on the part of both ***professional*** and ***commercial*** groups. We emphasize ***professional*** and ***commercial*** as if they were distinct, because one of the changes that the introduction of the Design-Build mode brings to procurement is the union of previously separate domains of responsibilities: that of the designers – professional, and that of the contractor – commercial. This change is significant as it breaks precedence with long established and zealously guarded traditions that delineate the respective jurisdictional territories of designers and contractors. We repeat that since the early 90s, there has been a noticeable move towards greater interest in Design-Build at a variety of levels; indeed at the institutional level, we observe a tendency to formalize the Design-Build practices.

In the United States of America, the recently established Design-Built Institute of America plays an important role in disseminating information. Also, promoting consistent practice within a range of accepted alternatives, it establishes in a formal fashion the 'rules of the game'. Similarly, in Canada there is a concerted effort on the part of The National Practice Program (NPP) – which is a partnership between the 10 Provincial Associations of Architecture and the Royal Architectural Institute of Canada – towards the compilation of what amounts to a code of practice, including a practice manual launched in 1996.

6 Stimulants to Design-Build

Procurement, according to Katsanis and Davidson [5], is quite properly seen as a set of key decisions in building – a set of decisions which establishes the framework for all subsequent building project activities: programming, design, manufacture, assembly and so on. Design-Build is viewed by many authors, [21, 22], as a building process or as a project delivery method, but according to Wundrum [23], Design-Build is not a process but rather an attitude. While there appears to be a consensus that Design-Build is a process, we also agree with Wundrum's assertion since it reveals a critical element in the understanding of this process.

Since procurement lies at the interface between demand and supply, procurement methods, to be successful, must match what the industry can offer with what the owners want. In other words, "procurers" (the intending building owners or their advisors) must constantly adapt their procedures to fit the organizations likely to work for them; conversely, these organizations are expected to be able to fit into the frameworks established by the currently prevailing procurement paradigms.

Nowadays, as is well known, owners, both public and private, are faced with an ever increasing challenge for obtaining maximum value for their construction dollars; this priority has a major influence on the demand side of the interface and consequently influences the forces on the supply side that aim at maintaining a balance in their favor. The unique and most important element of the Design-Build mode that is noted by the owners is the 'single point responsibility'. The organigrams shown on Figure 1 illustrate this feature and contrast it to the split responsibility under the traditional mode. However, in addition to singular responsibility, DBIA [24], lists the following benefits that arise from the Design-Build mode: 1. Quality; 2. Cost savings; 3. Time savings; 4. Potential for reduced administration burden; 5. Early knowledge of firm costs, and 6. Improved risk management.

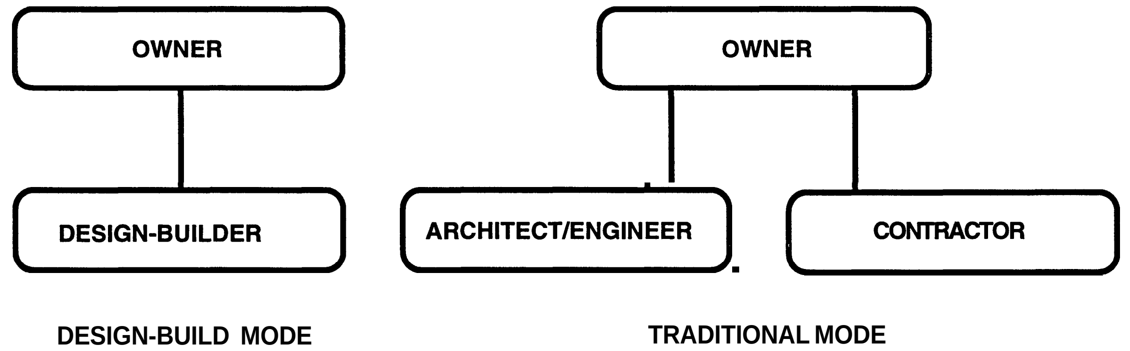

Figure 1. Organigrams indicating contractual links and ensuing responsibilities towards owners. Design-Build and traditional modes.

The models that describe the organization of Design-Build ostensibly emphasize, as we have said, the 'single point responsibility' assignment. The element of the single point responsibility has been identified by Katsanis and Davidson [4] as a desirable attribute and an influence in the shaping of organizational changes. However, in the case of Design-Build, for the owner to benefit from this arrangement, he/she must either have access to in-house expertise or retain the services of an independent consultant – a point we return to shortly. Furthermore these resources/services should be available and deliver the appropriate services in a timely fashion and with high a degree of completeness ***before the owner can make the decision to enter into the Design-Build mode.***

7 Problems with Design-Build

However, two levels of problems are associated with the practice of Design-Build. Firstly, the Design-Build process requires a high degree of sophistication on the part of the owner in order to deal with the complexity of drawing up contracts – a task traditionally reserved for the design professional. DBIA [24] states:

> "... The Owner should choose a design-build process variation based on factors such as project's complexity, funding, design intent, responsibility/risk allocation and other important issues. [...] For Owners who do not have in-house personnel with expertise in preparing and administering design-build request for proposals and contracts, an owner's design-build consultant may be retained to prepare scope definition and RFP documents, and to provide additional consulting services as needed."

Secondly, a major challenge exists in converting the owner's needs into adequate contracting language [24]. In effect, the expression of "what is required" in legally binding terms is increasingly difficult, if it takes place earlier on in the building functional analysis and design process. To develop and control a prescriptive technical specification is easy (even if the upstream steps leading to it may be complex). Developing and controlling a performance specification requires a considerable skill; producing and ensuring the respect of a functional program is extremely complex and indeed can often contain so many loopholes that almost any proposal may have to be accepted.

The owner has recourse to independent advice from the design professional on matters of need, functional performance and/or prescriptive specifications: The execution of these performance or prescriptive specifications becomes the responsibility of the builder. If a problem arises, the decision must first be made as to who is responsible for the problem - the designers or the builder. In the Design-Build mode, the owner, in exchange for having a single entity responsible for the designing and building phases, must assume responsibility for the preparation of the Design-Build RFP, which as we have just shown, is a very complex and risky task. Translating needs into functional specifications and then further translating them into performance and technical specifications requires a level of professional expertise-which are often outside the scope of the Design-Build team.

In point of fact, it appears that the Design-Build mode is an efficient organizational form which offers more benefits to the Design-Build team itself, particularly since it has become normalized to the point of becoming a well-defined processes. For example, Katsanis [25] found that Design-Build is preferred for a variety of reasons:

1. The inclusion of Design-Build in their repertory of work increases their market segment.
2. General contractors acting as builders in the Design-Build mode have a more prominent role in the building process and higher clout with designers. This situation works to their advantage when dealing with designers on other, traditional, projects.
3. Engineering firms also favor the Design-Build mode because it often means they receive functional or performance specifications and they can work on the final design with little or no risk of redesign effort.
4. Architects view Design-Build from a variety of perspectives as a function of the mission of their practice:
   a. Architects with a mission for "quality" architecture and "signature" type projects will shy away from Design-Build ventures unless they are granted "design license"; joint ventures (such as in Design-Build projects) are viewed as arrangements that take away control from the design process the architect must follow.
   b. Architects with professional experience on commercial real estate projects welcome the opportunity to take on Design-Build projects as it enhances their work portfolio and it is viewed as not much different from doing a project for a real estate developer with more or less "generic" performance specifications to be followed in the design:
   c. A third segment of architects views Design-Build as a delivery system that cuts into their professional domain by shifting the power to award a commission from the owner to the general contractor or developer. In such instances the response may be the formation of joint ventures to pursue Design-Build with entities that are deemed compatible with their professional status.

This reveals that, with the exception of architecture firms dedicated to "quality architecture", the principal participants of the building process, either willingly or by virtue of the market forces, are prepared to pursue the Design-Build mode. This observation combined with the difficulty of defining needs in contractually water-tight terms, raises serious concern about how the owners will go about getting from point A (the point in time when owners identify the need for a facility) to point B (the commencement of the Design-Build stage) i.e., providing the Design-Build team with clear and complete statements of required performance. It thus appears that Design-Build addresses single point responsibilities from the ***cost*** and ***time*** perspective but leaves out such issues as functional quality, appropriateness of a project and concerns over long term economic interests. Naturally, these issues are at the center of sustainability.

8 Will Design-Build be Practiced in 2020?

Let us now return to the paradigms that define the building industry environment. Katsanis and Davidson [4] have identified the complexity/specialization issue; they have shown how the dynamic reinforcing of complexity gives rise to specialization which in turn leads to fragmentation. The desire to overcome fragmentation by reducing the variety that one – the owner in this case – has to deal with endows the notion of simple point responsibility with great appeal

However, in assessing a new procurement method, it is essential to consider the idiosyncratic nature of the building industry. Groák [2] suggests that fragmentation is a normal attribute of the industry and that it arises from its intrinsic complexity. Attempting to deal with complexity by transferring complexity to another stage only increases the degree of fragmentation. Such is the effect of Design-Build. While it may group the designer and the builder into one entity, it excludes significant functions from the single point responsibility to the extent that new disciplines must now be created to take it over.

In other words, Design-Build creates some integration but, through the recognized shortcomings of its products, leads to countervailing "disintegration" through the isolation of the building owner, who is "left out in the cold".

How can this paradox be resolved? Either by wishing into being a new breed of sophisticated owner, skilled enough to establish and protect his/her interests against the Design-Build team, or – we suggest – by the spread of the network organization. We referred, earlier on, to the 'Rolodex' firm – a kind of ad-hoc network, established on a project-by-project basis from among a list of firms who feel able to work together. An extension of this idea is now emerging, namely the stable dynamic network of firms who are able to offer complete professional and technical services, but who, by virtue of their individual professional standings, are able to guarantee a balanced cooperation with the client-owner. Half way between the present-day fragmentation and the unwieldy integrated firms, we suggest that the network organization provides the vehicle of choice for the building owner as he/she approaches the problem of appropriate organizational design inherent in building procurement. Perhaps the present enthusiasm for Design-Build will be short lived.

References

1. Davidson, Colin H. (1988) "Building Team". In Wilkes, Joseph A., and Robert T. Packard, (Eds .). ***Encyclopedia of Architecture: Design, Engineering and Construction,*** New York, N.Y ., John Wiley and Sons Inc., Vol. 1, pp. 509-5 16.
2. Groak, Steven. (1994) "Is Construction an Industry?" ***Construction Management and Economics,*** Vol. 12, pp. 287-293.
3. Abdel Meguid, Tarek A. (1997) ***Managed Claims Procurement Strategy (MCPS): A Comparative Study of the Performance of Alternate Building Procurement Strategies.*** Doctoral Dissertation. Faculté de 1' Amemagement, Universite de Montreal, Montreal, Canada.
4. Katsanis, Constantine J. and C.H. Davidson (1995) "Horizon 2020: How Will North America Build?" ***International Journal of Architectural Management Practice & Research,*** No. 9, pp. 146-162.
5. Katsanis, Constantine J. and C.H. Davidson (1996) "Horizon 2020: Building Procurement and Industry Fragmentation, A North American Scenario." In R. Taylor (Ed.). ***CIB W92 Proceedings: North Meets South - Developing Ideas, Procurement Systems Symposium,*** Durban, South Africa, pp. 251-260.
6. Tait, Janice J. (1975) "Some Ways of Thinking about the Future", ***Industrialization Forum,*** Vol. 6, No. 5, pp. 13-26.

7. Levy, Ron. (1975) "Futures and Designers - a Brief Commentary", *Industrialization Forum*, Vol. 6, No. 5, pp. 53-56.
8. Senge, Peter M. (1990) *The Fifth Discipline - the Art and Practice of the Learning Organization,* New York, N.Y., Doubleday.
9. Hammer, Michael, and James Champy. (1993) *Re-engineering the Corporation: a Manifesto for Business Revolution,* New York, N.Y., Harper Business, a Division of Harper-Collins Publishers.
10. Betts, Martin, and Trevor Wood-Harper. (1994) "Re-engineering Construction: a New Management Agenda", *Construction Management and Economics*, Vol. 12, pp. 55 l-556.
11. Winch, Graham. (1989) "The Construction Firm and the Construction Project: A Transaction Cost Approach", *Construction Management and Economics,* Vol. 7, pp. 33 l-345.
12. Eccles, Robert G. (198 1) "The Quasifirm in the Construction Industry", *Journal of Economic Behavior and Organization,* Vol. 2, pp. 335-357.
13. Bröchner, Jan. (1990) "Impacts of Information Technology on the Structure of Construction", *Construction Management and Economics,* Vol. 8, pp. 205-218.
14. Russell, J. T., and W. R. Lane. (1990) *Kleppner's Advertising Procedure,* Englewood Cliffs, N.J., Prentice Hall.
15. Friedman, Andrew L. (1994) "The Information Technology Field: Using Fields and Paradigms for Analyzing Technological Change", *Human Relations,* Vol. 14, No. 4, pp. 367-392.
16. Best, Michael. (1990) *The New Competition,* Cambridge, Ma., Harvard University Press.
17. Nohria, Nintin. (1992) "Is a Network Perspective a Useful Way of Studying Organizations?" In Nohria, Nintin, and R. G. Eccles, (Eds.) *Networks and Organizations,* Boston, Ma., Harvard Business School Press, pp. l-22.
18. National Practice Program (1996) *Design-Build Project Delivery: Practice Manual,* Ottawa, Ont. Royal Architectural Institute of Canada.
19. Saint, Andrew. (1983) *The Image of the Architect, New* Haven, CT., Yale University Press.
20. Barrie, Donald S. and B. C. Paulson, (1978) *Professional Construction Management,* New York, McGraw-Hill Book Company.
2 1. Kluenker, Charles H. (1996) "The Construction Manager as Project Integrator" *Journal of Management in Engineering,* (March/April), pp. 17-20.
22. Natkin, Kenneth H. (1994) "Legal Risks of Design/Build", *Architecture,* (September), pp. 125-127.
23. Wundrum, Edward C. (1997) "Design-Build – A Successful Procurement Option" In Davidson, Prof. Colin.H., (Ed.). *Procurement - The Way Forward,* Montreal, IF Research Corporation, pp. 3 l-38.
24. DBIA (1994) *An Introduction to Design-Build,* Washington, D.C. Design-Build Institute of America
25. Katsanis, Constantine J. (1998) *An Empirical Examination of the Relationships Between Strategy, Structure and Performance in Building Industry Organizations.* Doctoral Dissertation. Faculté de 1' Amemagement, Universite de Montreal, Montreal, Canada.

Changing Consumption Patterns to Achieve Sustainable Development: Role of construction

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Abstract
At the Earth Summit in 1992, the nations of the world, through their leaders, committed themselves to achieving sustainable development. They recognised that, to achieve this aim, current patterns of consumption of all resources should be radically changed. This commitment has been "renewed" and reiterated at subsequent international meetings. The construction industry is a well-known massive consumer of natural resources. However, in most countries, the industry's practices and medium-term plans show that it is either unaware of, or indifferent to, the current international declarations and global consensus on sustainability.

This paper reviews the resolutions, declarations and proceedings of recent major international conferences, and other meetings, on the environment. It considers the role construction is expected to play in the efforts to achieve the aims and objectives stated in these resolutions and proceedings. It focuses on the efforts to change current consumption patterns in order to achieve sustainable development. It cites examples from the practices of the construction industry in Singapore. The paper advocates a "cradle to grave'? approach to the construction process, and highlights the need for teamwork both within the construction industry, and between the industry and related sectors, such as manufacturers of materials and components.
Keywords: Changing consumption patterns, sustainability, role of construction, teamwork.

1 Relationship Between Construction Activity and the Environment

It is now acknowledged that construction activities can have a a serious effect on the environment [1]. The first of these is the impact on land-use. Every construction project on a green field site takes land away from other activities, notably agriculture [2]. Construction invariably involves a modification of the land on which the item is located and in some cases, its environs (for example, in order to provide access to the constructed facility). This can have an adverse effect on ecosystems [3,4].

Second, construction uses a large amount of natural resources, many of which are non-renewable [5,6]. Generally, construction materials are being used at unsustainable rates. For example, construction is a major contributor to the exploitation of forest products which is leading to rapid deforestation (and the related environmental effects such as soil erosion) [7, 8]. In Singapore, the construction industry persists in its use of timber formwork despite encouragement by public-sector clients to use alternatives. This is so although, as a result of a shortage of timber, its cost has risen sharply [9].

Another issue relating to the use of construction materials is the amount of avoidable waste generated. For example, it is estimated that the average wastage level for the Singaporean contractor is 8 per cent whereas Japanese contractors in Singapore (which also use subcontractors) can keep waste to within 4 per cent [10]. The Ministry of the Environment estimated that in the early 1990s, construction wastes in Singapore amounted to 200,000 tonnes annually; 40 per cent of this was from timber [11]. Also observed in Singapore is that owing to the very high waste disposal charges at landfill sites, some contractors try to dispose of their wastes illegally by dumping them at unauthorised sites, or burning them in open fires [12]. Moreover, poor housekeeping, carelessness or ignorance results in the spillage of substances which are washed into the environment, or which may form toxic fumes upon decomposition [13].

Third, construction leads to a high level of energy consumption [5]. Much of this is accounted for by the extraction and processing of materials. Some metals used in construction, such as aluminium, steel and zinc, as well as plastics are highly energy intensive. Smaller amounts of energy are used in transporting the materials to the construction sites, and in their installation during site processes. Moreover, with the completion of every new constructed item, additional demands are put on increasingly scarce energy and water supplies.

The final major environmental consequence of construction activity worth highlighting here is its contribution to air pollution. Particles of various sizes, some of which are harmful to humans, are released in the production and transportation of materials such as cement and quarry products. In Singapore, there are stringent regulations on the emission of dust from items being transported [14], and contractors and suppliers must take action to limit emissions from materials during transportation.

Following the realisation of the environmental impact of construction activity, some work has been done on how the adverse effects can be reduced. Some action has also been taken by governments, professional institutions and companies to address these issues. The concept of *sustainable construction* has emerged. It is pertinent to review, briefly, some recent works on the issue. This review in the next section focuses on the suggestions made by the authors with respect to the actions which the industry must take in order to attain sustainability in its operations.

2 Some Past Works on Sustainable Construction

Samuels and Prasad (1994) [15] discussed the interaction between the built and natural environments, and charted the developments in terms of social responsibility and environmental accountability, environmental and energy auditing, ecologically sustainable design and energy standards and labelling. They offered suggestions for reducing the negative impacts of socio-economic development on the environment. Ofori (1992) [3] reviewed the environmental consequences of construction operations and suggested that in order to develop a culture of environmental protection in the construction industry, the client must be motivated to adopt the environment as a project objective.

Moavenzadeh (1994) [16] considered the potential for positive contributions by the construction industry to efforts to protect the environment, and identified relevant business opportunities. Griffith (1994) [17] proposed a framework for a structured environmental management programme in the construction industry. Hill and Bowen (1997) [18] reviewed the concept of *sustainability* in general, and *sustainable construction* in particular. They stressed the importance of environmental management systems (EMS) within construction organisations to guide construction, operation and decommissioning, and offered an EMS framework.

The next section considers the themes and relevant main conclusions of some recent major meetings on environmental issues. After briefly discussing “sustainability” in general, it considers one of its main areas of focus, “sustainable consumption”, and finally, “sustainable human settlements”.

3 Sustainable Consumption

3.1 Sustainability

Following the work of the Bruntland Commission (1987) [19], which first offered a widely accepted definition for *sustainable development,* there have been several international conferences on *sustainability.* At the United Nations Conference on Environment and Development in Rio de Janeiro-, Brazil in 1992, the world’s leaders committed their countries to *sustainable development.* They adopted Agenda 21, whose principles have guided actions and discussions on sustainability. Whereas there have been some achievements, there is a lack of progress in many of the objectives, targets and actions set at the Rio Summit [20]. The failure of the follow-up meeting, Rio Plus Five in 1997 to produce a final document shows the continuing controversy and difficulty in these matters. In recent years, an aspect of sustainability which has received much attention is the issue of *sustainable consumption.*

3.2 Changing Consumption Patterns

The concept of *sustainable consumption* is based on the realisation that current levels of consumption, and present production methods are leading to the depletion of the known resources [21, 22]. They are also producing by-products and wastes which are adversely affecting the quality of the environment. Thus, it is argued that consumption must be sustainable, and that a change in current consumption patterns is vital [8].

Agenda 21 did not specifically define *sustainable consumption* but noted that policy should focus on: "the demand for natural resources . . . and the efficient use of those resources consistent with the goal of minimizing depletion and reducing pollution". The first Oslo Symposium on Sustainable Consumption in 1994 [23] observed that current resource flows induce pollution, resource depletion, energy consumption, biodiversity and landscape destruction which appeared unsustainable by any standard. It defined *sustainable consumption* as:

> ... the use of services and related products which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardise the needs of future generations.

The main working document of the second Oslo meeting in 1995 [24] expanded this , definition and described *sustainable consumption* as:

> ... an umbrella term that brings together a number of key issues, such as meeting needs, enhancing the quality of life, improving resource efficiency, minimizing waste, taking a life cycle perspective and taking into account the equity dimension. Integrating these component parts is the central question of how to provide the same or better services to meet the basic requirements of life and the aspirations for improvement for both current and future generations.

The Discussion Paper of an Expert Group Meeting on "Changing Consumption Patterns in Human Settlements" in New York in April 1997 [25] cited the following trends in the consumption of natural resources: (i) rapid growth in energy consumption, with a high proportion of losses through inefficient use and resulting in environmental externalities which affect human health, ecological stability and economic development; (ii) expansion of the transport sector owing to increased urbanisation; (iii) acute shortage of water in many cities and regions, with rapidly decreasing reserves; (iv) rapid loss of both tropical and temperate forests, resulting in erosion, soil degradation and loss of biodiversity; (v) depletion of mineral resources and the wide and major resulting environmental impacts; and (vi) increasing levels of waste generation owing to these high volumes of consumption. It suggests that the main forces driving these trends are global increases in population and economic growth resulting in rising income levels. A major contributory factor to stress is poor efficiency in usage (as in the use of energy inefficient vehicles), and inadequate management (as in the waste of water through leakage during distribution).

The Discussion Paper notes that under there are particular areas of stress in several countries. Many of the resources identified as being in short supply, such as timber, minerals and water, are direct inputs of construction, although the shortages are at various levels of criticality with respect to different materials and countries. Construction activity can also contribute to the better management of the other resources, such as water (through the repair and maintenance of distributing systems).

3.3 Sustainable Human Settlements

A recent gathering of national leaders which is of greatest relevance to construction researchers and practitioners is the United Nations Conference on Human Settlements (Habitat II) in Istanbul, Turkey in June, 1996. The main document, the Habitat Agenda [26], presents the goals, principles, commitments and Global Plan of Action of the conference. As at all major United Nations conferences, the participants made some bold declarations. They declared that they were:

> … committed to political, economic, environmental, ethical and spiritual vision of human settlements based on the principles of equality, solidarity, partnership, human dignity, respect and cooperation. We adopt the goals and principles of adequate shelter for all and sustainable human settlements development in an urbanizing world. (p. 6)

The contents of the Habitat Agenda are of direct concern to construction as the industry plans, designs, constructs, maintains, reshapes, upgrades and ultimately, demolishes the human settlements. Construction also obtains much of its inputs from these settlements. As indicated in the above quotation, Habitat II stressed the concept of *sustainable human settlements* which it defined as follows:

> Sustainable human settlements development ensures economic development, employment opportunities and social progress in harmony with the environment. It incorporates, together with the principles of the Rio Declaration . . ., the principles of the precautionary approach, pollution prevention, respect for the carrying capacity of ecosystems, and preservation of opportunities for future generations. Production, consumption and transport should be managed in ways that protect and conserve the stock of resources while drawing upon them. (p. 7)

The Habitat Agenda elaborated on the concept of *sustainable human settlements:*

> Sustainability of human settlements entails their balanced distribution . . . in keeping with national conditions, promotion of economic and social development, human health and education, and the conservation of biological diversity and the sustainable use of its components, maintenance of cultural diversity as well as air, water, forest, vegetation and soil qualities at standards sufficient to sustain human life and well-being for future generations. (p. 8)

Thus, construction activity must be *sustainable*. Indeed, among 14 "objectives" stated in the Habitat Agenda was the following:

> Promoting locally available, appropriate, affordable, safe, efficient and environmentally sound construction methods and technologies in all countries . . . at the local, national, regional and subregional levels that emphasize optimal use of local human resources and encourage energy-saving methods and are protective of human health. (p. 12)

The next section considers possible future directions in construction in the light of the conclusions of major international conferences outlined above.

4 The Future

Ensuring a change in current patterns of consumption is a key issue to governments, most of which are taking measures on both the supply and demand sides. These include statutory and regulatory measures, as well as economic instruments (charges, taxes and subsidies. Action is required several areas. Among the objectives under the goal of *sustainable human settlements* in the Habitat Agenda is the following:

> Promoting changes in unsustainable production and consumption patterns, particularly in industrialized countries, population policies and settlement structures that are more sustainable, reduce environmental stress, promote the efficient and rational use of natural resources – including water, air, biodiversity, forests, energy sources and land – and meet basic needs, thereby providing a healthy living and working environment for all and reducing the ecological footprint of human settlements. (p. 14)

The United Nations Centre for Human Settlements (1997) [25] suggests that the following should act as indicated: (i) governments – introduce natural resource accounting, encourage industry to improve efficiency of resource use, promote sustainable consumption through pricing., incentives, and eco-labelling schemes; (ii) industry – lead the drive to achieve eco-efficiency by improving efficiency in resource usage, minimising waste in production, recycling waste, and increasing research and development on low waste and cleaner technologies; and (iii) international community – establish and promote energy and material efficiency standards, assist developing countries to acquire eco-efficient technologies, and support the exchange of information on indicators and best practices.

On the basis of the principles of sustainable consumption outlined above, the United Nations Centre for Human Settlements (1997) [25] suggests that consumption in human settlements must fulfil the following minimum criteria: (i) it should meet the basic needs of populations and contribute to raising the quality of life; (ii) it should not irreversibly degrade or deplete the stock of resources; and (iii) it should not lead to irreversible degradation of the environment through the accumulation of emissions and wastes. This summary is a useful framework for evaluating construction activities.

The greater international focus on efforts to change consumption patterns should give greater impetus to the drive towards *sustainable construction.* The construction industry must play its part in the effort towards sustainable development in general by changing the levels at which it consumes resources, as well as the types of resources which it uses. The industry must consider every aspect of the construction process, from the extraction of the material inputs to the eventual demolition and disposal of the completed item. It should study all the inputs, both direct and indirect, as well as all the outputs, by-products and wastes. The industry must find substitutes for where acute stress is evident , and where the consequences of non-sustainability is serious. It should also minimise wastes through improved management on site.

The industry should respond in a more co-ordinated manner. So far, in each country, the responses have been by individuals, companies, or professional bodies. Much can be gained from synergistic action. The Habitat Agenda [26] stresses "partnerships", among countries, among all interested or concerned parties within countries: public, private, voluntary, community-based organisations, co-operatives, non-governmental organisations and individuals. These can integrate and mutually support objectives of broad-based participation through forming alliances, pool resources, share knowledge, contribute skills and capitalise on the advantages of collective action.

5 Conclusion

The construction industry should follow the discussions on environmental issues at the international level, since the commitments made, and conclusions reached at these meetings indicate imperatives for action in all countries and all sectors. These inform and shape policy, and will eventually form the basis of competition among business enterprises. The concept of changing consumption patterns in the context of sustainable human settlements offers a useful framework for developing good practice in construction, and should propel the drive towards *sustainable construction.*

6 References

1. United Nations Centre for Human Settlements (UNCHS) (1993) *Development of National Capacity for Environmentally Sound Construction.* Nairobi.
2. United Nations Centre for Human Settlements (UNCHS) (1990) *People, Settlements, Environment and Development.* Nairobi.
3. Ofori, G. (1992) The environment: The fourth construction project objective? *Construction Management and Economics,* **10**, *369-395.*
4. Ofori, G. (1993) The environment as a construction project objective. In Briffett, C. and Sim, L.L. (eds.) *Proceedings: Seminar on Environmental Issues in Development and Conservation,* Singapore, pp. 52-56.
5. Lenssen, N. and Roodman, D.M. (1995) Making better buildings. In Worldwatch Institute (ed.) *State of the World 1995.* Norton, New York, pp. 95-l 12.

6. Young, J.E. and Sachs, A. (1995) Creating a sustainable materials economy. In Worldwatch Institute (ed.) *State of the World 1995.* Norton, New York, pp. 76-94.
7. Worldwatch Institute (1995) *State of the World 1995.* Norton, New York.
8. Brown, L.R., Flavin, C. and Kane, H. (1996) *Vital Signs 1996: The trends that are shaping ourfuture.* Norton Co. and Worldwatch Institute, New York.
9. Low, C.K. (1996) Environmental Friendly Architecture in Singapore. Unpublished Dissertation, National University of Singapore.
10. Construction Industry Development Board (1989) *Report on the Cost Competitiveness of the Construction Industry in Singapore.* Singapore.
11. Ng, P.W.M. (1993) Environmentally sustainable construction. In Lee, S.E., Tham, K.W. and Sim, L.L. (eds.) *Green and Healthy Buildings.* Centre for Building Performance and Construction, National University of Singapore.
12. Hui, J. (1995) Environmental policy and green planning. In Ooi, G.L. (ed.) *Environment and the City.* Times Publishing, Singapore, pp. 13-46.
13. Tan, A.T.K. (1997) IS0 14000: A Practical Approach for the Local Construction Industry. Unpublished Dissertation, National University of Singapore.
14. Ministry of the Environment (1993) *Environmental Protection in Singapore: A handbook.* Singapore.
15. Samuels, R. and Prasad D. K. (eds.) (1994) *Global Warn-zing and the Built Environment,* 1 st Edition. Spon, London.
16. Moavenzadeh, F. (1994) *Global Construction and The Environment: Strategies and Opportunities.* Wiley, New York.
17. Griffith, A. *(1994) Environmental Management in Construction.* Macmillan, London.
18. Hill, R.C. and Bowen, P. (1997) Sustainable construction: Principles and a framework for attainment. *Construction Management and Economics,* **15**, 223-239.
19. Bruntland Commission (1987) *Our Common Future.* Oxford University Press, Oxford.
20. United Nations (1992) *United Nations Conference on Environment and Development.* Rio de Janeiro, Brazil.
21. Van Pelt, M.J.F. (1993) *Ecological Sustainability and Project Appraisal.* Avebury, Aldershot.
22. Organisation for Economic Co-operation and Development (1996) *Integrating Environment and Economy: Progress in the 1990s.* Paris.
23. Symposium on Sustainable Consumption (1995) Summary of Issues Raised at the Symposium. 19-20 January.
24. Oslo Ministerial Roundtable Conference on Sustainable Production and Consumption (1995) *Elements for an International Work Programme on Sustainable Production and Consumption.* Oslo, Norway, 6- 10 February.
25. United Nations Centre for Human Settlements (UNCHS) (1997) Changing Consumption Patterns in Human Settlements. Discussion Paper, Expert Group Meeting and Follow-up Workshop, New York, 9-l 1 April.
26. United Nations Centre for Human Settlements (UNCHS) (1996) *The Habitat Agenda: Goals, principles, commitments and Global Plan of Action.* United Nations Conference on Human Settlements (Habitat II), Istanbul, Turkey, 3-14 June.

Sustainable Building - a Swedish national research program

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Abstract
The Foundation for Strategic Environmental Research (MISTRA) was established in 1994. The purpose of the foundation is to fund research of strategic importance for a good living environment, and it is distinguished by the special nature of its activities: concentration of efforts, projects and programs that span the boundaries between disciplines, establishment of networks nationally and internationally, promotion of training and recruitment of researchers, collaboration between universitites and industry.

In 1997, a total of 18 MISTRA program had been granted funding. One program, *Sustainable Building*, is linked to construction industry and property management. The program started in January, 1997, and is planned to run for six years. The program focuses the building as a system, composed of technical sub-systems, in a life cycle perspective, and the buldings impact on the out-door environment. The goal of the program, condensed into two major issues are: *Resource efficiency* and *Emission control.* The program comprises three scientific subprograms:

1. Resource Economy - The Building as a System
2. Adaption of Materials and Components to an Eco-Cycle System
3. Implementation of Sustainable Building,

as well as an additional subprogram dealing with program coordination and knowledge dissemination. Four universities and one research institute cooperate within the program. Departments of Architecture, Civil Engineering, and Building Economics take part.

Cooperation between the projects and subprograms is extensive, and synthesis discussions form an important part of the program. Project results are scarce so far, due to the limited time the program has run. The experiences from this kind of cooperation, interdisciplinary within the program and between research and practice, are favourable, especially in the network of PhD students.
Keywords: Sustainable building, multidisciplinarity, industry cooperation, implementation

1. Introduction

The Foundation for Strategic Environmental Reserach, MISTRA, funds research of strategic importance for a good living environment. Activities promoted by the foundation aim at:

- concentration of efforts
- projects and programs that span the boundaries between disciplines
- establishment of networks nationally and internationally
- promotion of training and recruitment of researchers
- research centres in close association with universities
- collaboration between universities and industry
- mobility of researchers.

In the beginning of 1998, MISTRA has approved 18 large research programs, covering various industrial sectors as well as broad environmental and societal issues. One MISTRA program is aimed at building and real estate management - “Sustainable Building”. The first program period comprises years 1997-99. A second period is planned 2000-02.

2. The Program

Researchers at Schools of Architecture, Civil Engineering, and Technology Management and Economics, of the universities of technology in Göteborg, Lund, and Stockholm, and at the National Testing and Research Institute cooperate in this program. The program is managed by a group of three subprogram coordinators chaired by a program director, all four professors at the universities of technology. The executive committee of the program is formed mainly by leading industry representatives.

2.1 Range and scope

The program deals with the building and its environmental impact from a life-cycle perspective. “Building” here denotes primarily housing and commercial buildings, not, in the first place, road construction and other civil engineering artifacts. The building is regarded as a system, including its immediate surroundings, such as foundation work and the building’s connection to urban infra-structure. The emphasis is on the outdoor environment. The entire lifetime of a building includes programs, plans and briefs, design, construction, use and maintenance, reconstruction and changes, final demolition or dismantling followed by the handling of residue products and waste material. Products and processes are equally important.

Building materials and parts composing the building all have a history before they are contained in the building, as well as a future after the lifetime of the building. Life-cycle aspects of this kind are treated in the program insofar as they are needed to establish the total environmental load of the building. Aspects of technology, architecture, economics and management are studied. A basic knowledge of the mass and energy flows in the building stock and the building sector is necessary.

2.2 Goals

In late 1997, the Swedish government's commission on ecologically sustainable development set three goals for ecologically sustainable development (Government Communication 1997/98: 13):

"Environmental protection: Emissions must not harm human health or exceed the capacity of nature to absorb them. Natural cycles must be protected; harmful man-made substances should not occur in nature. Biological diversity and valuable cultural environments must be protected.

Efficient utilization: Energy and other natural resources must be used much more efficiently than is the case today.

Sustainable supplies: Agriculture, forestry and fisheries must be managed in such a way as to allow regeneration of resources. The aim must be to recycle materials in ecocycles and to use renewable raw materials."

We use the goals set by the government for sustainable development as a framework when defining goals for the Sustainable Building program:

Environmental Protection: Building materials and processes may give rise to harmful emissions. Important issues in this respect are:

- the amount and distribution of known harmful substances in existings buildings and the handling of such substances
- the identification of harmful emissions from building materials.

Efficient Utilization: This is the core issue in the development of sustainable building, comprising:

- the use of energy during the entire life-time of buildings
- the use of materials, inclusive of the life-cycle of materials and issues of recycling
- the use of land property for buildings and waste deposits.

Sustainable Supplies: Within the field of sustainable supplies, relevant issues for the program are:

- service life and recycling of materials, components and whole buildings
- renewable resources.

The goals described above are valid as a whole, but can be condensed into two major issues:

- *Resource Efficiency*
- *Emission Control*

2.3 Priorities

In a program devoted to a field as complex as building and real estate management, it is a challenge to find suitable ways to substantial and visible results within the limits set by time and money. We want to choose research subjects according to the anticipated impact of the results in total on practice. Several aspects are then considered:

- The strategic importance for industry/society in terms of quality and/or quantity
- The potential for penetration into practice
- The target group and its ability to utilize the results
- The public interest
- The importance in the context of the program.

With regard to these aspects, the program particularly stresses measures concerning the existing stock of buildings, energy use during the life-time of buildings, recycling issues, materials of special environmental influence, strategic methodology development, and implementation issues.

The training and recruitment of researchers - one of MISTRAs expressed goals - is of special importance in building and real estate management. We want the program to furnish the future industry with highly competent persons able to cope with complex environmental problems and to act as intermediaries between building practice and research. To this end, projects within the program are adapted to PhD study programs. Each project is led by a senior researcher and allows for one or more PhD students.

3. Program Structure

The program comprises three scientific subprograms:

1. Resource Economy – the Building as a System
2. Adaption of Materials and Components to an Ecocycle System
3. Implementation of Sustainable Building.

Each subprogram is held together by a coordinator. Projects within one subprogram are closely connected to each other, not least methodologically. Contacts between projects from different subprograms, however, are equally important. Aspects treated within Subprogram 3, for instance, will penetrate the program as a whole.

The structure of the program allows for, and invites, new projects. New projects of high priority are meant to be initiated, some of them with substantial commitment from industry. A capacity for project leadership, tutoring and supervision is reserved for such projects. Closely related projects with other principals are invited to join in comprehensive program activities, for mutual benefit, in the capacity of liaison projects.

3.1 Subprogram 1: Resource Economy - the Building as a System

The main purpose of this subprogram is to formulate conditions for an effective use of resources throughout the life cycle of buildings, to promote the use of renewable resources and to efficiate the use of non renewable resources. The building in its entirety is studied, and the research work is focussed on both new and existing buildings. The impact of various measures on the building stock as a whole is considered. Input of environmental data is needed, for instance, on life-cycle assessment of building materials and components, and on the pollutive effects on air, soil and water of the used resources (Subprogram 2). The prerequisites for the implementation of obtained results, for instance economic consequences, will be studied in cooperation with Subprogram 3.

Research fields specially addressed within subprogram 1 during 1997-99 are:

- Building stock studies, mass and energy flows
- The environmental impact and resource effectiveness of building engineering and services systems
- Resource effective practice of recycling
- Assessment and process studies of green projects.

3.2 Subprogram 2: Adaption of Materials and Components to an Ecocycle System

Eco-cycle adapation includes resource cycles of different types in building, maintenance and management as well as the adaption to the eco-cycles of nature. This subprogram aims at preventing building activities to generate systematically increased amounts of hazardous substances in the environment, and to make it possible to eliminate, isolate or treat in closed loops any hazardous substances present in building processes. Life Cycle Assessment methodology applied to building processes and products form an important part of the subprogram. The emission of more or less hazardous substances from building materials are studied, both with respect to their impact on the assessment process, and as a part of the deterioration mechanisms. The environmental impact of building materials is studied with respect to, e.g., service life, recycling potential, and chemical treatment.

Research fields specially addressed within subprogram 2 during 1997-99 are:

- LCA methodology studies
- Emissions from building materials
- Groups of building materials: concrete, polymerics, timber.

3.3 Subprogram 3: Implementation of Sustainable Building

Under this subprogram organizational, economic and other factors influencing the implementation of sustainable building are studied. Often it is not only a lack of technical know-how that hinders environmentally adapted building, but rather the economic and organizational systems which influence decision-making and actions. The picture becomes complicated by the great number of organizations with distinct objectives, values and fields of competence, all of which are active in the building process. For this reason, systems for spreading knowledge and information to and for motivating groups of actors involved in the building process are studied. Subprogram 3 applies social science and economics on building and construction. The aim of the program’s studies of the steering systems and economy in building is to obtain greater understanding of the decision-making process in building, and of appropriate measures which will motivate the actors in the building sector to act in a more environmentally sound way.

Research fields specially addressed within subprogram 3 during 1997-99 are:

- Decision-making processes and environment monitoring systems in organizations
- Economic analysis applied to the program’s technical projects
- Life cycle economy
- Decision-making processes in the design stage with a focus on factors influencing the choice of materials and technical solutions.

3.4 Projects, Agenda 1997-1999

		Start
1.1	The Building Stock - Resource Deposits and Resource Flows *Project Leader AA4 Wilhelmsen*	March 1998
1.2	Assessing the Environmental Impact of Building Engineering Systems *Project Leader Arne Elmroth*	
1.2A	Modern Buildings *PhD Student Karin Adalberth*	Jan 1997
1.2B	Older Buildings *PhD Student Anders Almgren*	May 1997
1.3	Building Services Systems *Project Leaders Lars Jensen, Anders Svensson* *PhD Student Mats Dahlblom*	Jan 1998
1.4	Design for Recycling *Project Leader Bertil Fredlund* *PhD Student Catarina Thormark*	Jan 1997
1.6	Environmental Design Strategies *Project Leader Michael Eden* *PhD student Paula Femenias*	March 1998
2.1	LCA Methodology for Sustainable Building *Project Leader Kai Ödeen*	
2.1.1	LCA in the Usage Phase *PhD Student Jacob Paulsen*	Jan 1997
2.1.2	Allocation and Boundary Setting *PhD Student Wolfram Trinius*	Jan 1997
2.2	Hazardous Substances Emitted from Building Materials *Project Leader L-O Nilsson* *PhD Student Åse Andersson*	Aug 1997
2.3	Recycling Concrete *Project Leader Ralejs Tepfers* *PhD Student Mats Karlsson*	Apr 1997
2.4	Polymeric Products in Sustainable Buildings *Project Leaders Thomas Gevert, Ignacy Jakubowicz* *PhD Student Nazi Yarahmadi* *PhD Studies Supervisor Thomas Hjertberg*	Aug 1997
2.5	Environmental Impact of Treated Wood *Project Leader Kai Ödeen*	March 1998
3.1	Obstacles and Incentives to Implementation of Sustainable Building *Project Leader Gösta Fredriksson* *PhD Student Jonas Birgersson*	May 1997
3.2	Economic Analysis in an Environmental Context *Project Leader Gösta Fredriksson* *PhD Student Pernilla Gluch*	March 1998

Liaison Projects

1.7	Resource Economy Design *Project Leader Jan Gustén* *PhD Student Eva Johnssson*	1997
2.1.3	LCA and Indoor Environmental Assessment *Project Leader AM Tillman* *PhD Student Åsa Jönsson*	1997
3.3	Design Choices and Service Life *Project Leader Gösta Fredriksson* *PhD Student Thomas Björklund*	

4 Subprogram 4: Program Coordination and Knowledge Dissemination

This fourth subprogram is concerned with cross-disciplinary communication within the program itself and between the program and the users of its results.

The aim of activities within this subprogram is to bring researchers, PhD students and subject matters in different disciplines togther, to develop knowledge traversing disciplinary boundaries and to initiate joint enterprises. Program seminars are held regularly, where all researchers active in the program meet. Seminars deal with, for instance, methodological issues common to several projects, or review state-of-the-art within one subprogram or within the program as a whole. Synthesis discussions form an important part of the seminars. PhD courses are arranged, during 1998 on LCA methodology and on the development of building engineering and services systems during the twentieth century. Common databases on reference buildings, literature, and LCA data are set up.

Activities turned outwards aim at building bridges between building practice and research, to engage researchers in development projects and to involve people from the industry in the program. This ambition stretches beyond the actual research program. Projects with other principals and focusing on issues of vital interest to the program are invited to attach to the program as liaison projects, and to take an active part in all activities in subprogram 4.

Economic support from industry is a two-fold benefit, in that an organization investing money in the program also invests interest and will ask for results. One form of support especially favoured in the program is called "industry linked PhD students". In such cases, a young civil engineer or architect employed by an industrial or consultant company is assigned to complete a PhD program at a university department within the scope of his/her employment. So far, one industry linked PhD student is engaged in the program, and discussions are on their way in a second case.

5. Results and conclusions

This program has run only for one full year, and research results are scarce so far. Some of the projects will be presented at this Congress (2.1, 3.1). Forthcoming results from projects will be published according to disciplinary traditions. However, the results in total from this program are intended to give more than just all single project results added together. Synthesis discussions form an important part of the program from the very beginning, and will be stressed more and more. The synthesis work is one of the responsibilities of the Program Management Group, and the Executive Committee plays an important role in the discussions.

Our experiences from the work so far show both difficulties and advantages connected to cross-disciplinary networking. Holding together a group of thirty researchers and PhD students, active in half as many projects in different university departments, takes a lot of time and creative thinking. It is essential, to motivate people to work towards a common goal, that everybody knows and acknowledges the aims, content and goals of the program. This calls for frequent meetings, virtually and in reality, where experiences and problems can be shared. We have found the network to be especially valuable for the PhD students, who play a very active role.

The cooperation and respective roles of the Executive Committe and the Program Mangament Group is another important issue which has to be further explored in future, in order to take full advantage of the possibilities this kind of organisation of sectorial research gives for promoting the integration of research and practice.

6. Management Structure

Executive Committe

Gösta Blücher, Chairman	Director General, National board of housing and planning
Roland Akselsson	Professor, Industrial Engineering, Lund University
Bernt Johansson	President, Skandia Real Estate
Per Westlund	Vice-president, Skanska AB
Knut Wickberg	Director, Scancem
Karin Wiklund	President, Stockholm Cooperative Housing Association

Program Management Group

Anne Marie Wilhelmsen, Program Director	Professor, Building Design and Construction, Chalmers University
Arne Elmroth, Coordinator Subprogram 1	Professor, Building Physics, Lund Univerisity
Kai Ödeen, Coordinator Subprogram 2	Professor, Building Materials, Royal Institute of Technology
Gösta Fredriksson, Coordinator Subprogram 3	Associate professor, Build. Economics & Construction Management, Chalmers

Scientific Advisory Group

William Addis	PhD, Dep. of Construction Management & Engineering, The University of Reading
Roger Baldwin	Head of Department, Building Research Establishment, Garston, Watford, UK
Erik Christophersen	PhD, Danish Building Research Institute, Hörsholm, Denmark
Niklaus Kohler	Professor, Institut für Industrielle Bauproduktion, University of Karlsruhe, Germany

References

1. MISTRA, Foundation for Strategic Environmental Research (1993) *Statutes*, Stockholm.
2. The Swedish Government's Commission on Ecologically Sustainable Development (1997) *Ecological sustainability,* Government Communication 1997/98: 13, Stockholm.
3. Building Design, Chalmers University of Technology (1995) *Sustainable Building. An Ecocycle System in Building and Construction. A Proposal to the Foundation for Strategic Environmental Research,* Goteborg.
4. Building Design, Chalmers University of Technology (1997) *Sustainable Building - A MISTRA Program. Program Plan* 1997-99, Goteborg.

Sustainable construction in Finland: approach and best practices

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Abstract
This paper describes:

- the state-of-the-art of construction and environment in Finland
- current status of the national environmental technology program
- selected best practices along sustainable building process
- recommendations to the building sector for the future.

The building sector represents almost half of the primary energy produced in Finland: 34 % is consumed for space and domestic hot water heating and electricity used in households and 10 % for building production. Construction and demolition waste is produced at a rate of 1,5 million tons annually. 20-30 % of the building waste is currently recycled.

Our main ongoing research and development effort is the technology program: Environmental Technology in Construction (1995-1999), coordinated by the Technology Development Centre. It has an estimated budget of 20 million USD, of which industrial cofinancing share is about a half. The program aims at developing methods and technologies for environmentally sound construction to be implemented in enterprises. The program consists of five research and development priority areas: ecobalance and life cycle, design guidelines and procedures, products and production technologies, pilot construction projects and environmental geotechnics.

Different actors within the building process have already established their sustainable best practices. This paper presents selected examples of ecological and energy-conscious buildings, ecological criteria for experimental construction, business based on waste recycling, and electric and district heating energy plant. Finally, the issue of environmental management systems is touched, and recommendations to the building sector are given for the future.
Keywords: building, environment, sustainable construction

1 Construction and environment

The most significant quantifiable environmental impact of the construction sector is emissions due to energy consumption. The building sector in Finland presents 44 % of the total energy consumption: 34 % for heating of buildings and electricity used in households and 10 % for building production (out of which 70 % comes from manufacturing of products and 30 % from transportation and building sites). In addition, 3 % of the total energy is consumed by production of building materials and products for exportation.

Over 80 million tons of building materials and natural resources are used annually in construction in Finland. The amount is fourfold compared to municipal waste. About 7- 10 million tons of waste are generated every year at demolition and renovation sites, in new construction, and in civil engineering. The goal is to increase the utilization of construction waste from the current 20-30 % to 70 % by 2005. [1]

In Finland, the availability of free space, and air and water of good quality, is not seen as a problem to be solved and that is not striving us towards environment-saving solutions, like in some other countries. The climatic conditions in the North of Europe are cold stimulating us to energy saving thinking and acting – also because we are depending on imported energy. Sustainable development as a target is accepted and the means for co-operation and large-scale responsibility exist. The starting point for developing and implementing sustainable construction is good for us both within our borders, and abroad.

2 Sustainable construction

Sustainable development is often considered to contain ecological and economical, social, and cultural aspects. In this paper, sustainable construction stands for ecologically sustainable construction, which means essentially management of biodiversity, tolerance of the nature, and saving use of resources. Achievement of ecologically and economically sustainable construction enables socially and culturally sustainable construction.

According to our current definition [2], sustainable construction in its own processes and products during their service life aims at minimizing the use of energy and emissions that are harmful for environment and health, and produces relevant information to customers for their decision making. To building construction this means:

- intensified energy-efficiency and extensive utilization of renewable energy sources
- prolonged service life as a target
- saving of the natural resources and promotion of the use of by-products
- reducing waste and emissions
- recycling of building materials
- supporting the use of local resources
- implementation of quality assurance and environmental management systems.

The desired state prevails environmentally responsible industry and building owners together with environmentally conscious consumers.

3 Environmental technology in construction

Technology programs are an essential part of the Finnish innovation system to encourage the technological development in industry. Environmental Technology in Construction [3] is one of these technology programs coordinated by the Technology Development Centre (Tekes) [4]. It was launched in 1995 to aim at developing environmental-conscious techniques and methods in the field of construction. It has an estimated budget of 20 million USD to be covered by about 50 % by the participating companies.

The program deals with: .

- environmental impact assessment methods
- ecological design methods, data bases and programs
- utilization of industrial by-products in construction and geotechnics
- reconditioning of contaminated soil and protection of ground water
- production methods and products that save energy, reduce emissions and make use of recyclable construction materials
- manufacturing equipment, machinery and testing methods for the above.

Alongside this program, the Academy of Finland launched a basic research program for Ecological Construction. Development work for ecological urban construction is carried out in cooperation with the Ministry of Environment and the Finnish Association of Architects, whose ecological urban development is part of this technology program for pilot construction of new solutions.

The ongoing research and development projects are focused to the following five main areas:

- environmental assessment of buildings and building products
- design guidelines
- products and production technologies
- experimental construction
- environmental geotechnics.

The projects within the first area deal with the framework, procedures and methods for the environmental assessment of buildings products together with the structure, format and quality of the environmental information to be used by designers and manufacturers. The second area results in guidelines, methods and tools for clients and designers. International information and technology transfer with organizations, such as CIB, RILEM or Green Building Challenge form part of that work. The third area focuses on improving production processes, waste management, recycling technologies and new products. The fourth area aims at implementing urban environment following the principles of a sustainable future. It consists of experimental construction of new buildings and renovation.

4 Best practices

The following examples are presented to illustrate how different aspects of sustainable construction have been implemented into practice:

- environment-conscious buildings

- criteria for ecological neighbourhood
- business based on waste recycling
- sustainable electric and district heating energy plant.

4.1 Environment-conscious buildings

An ecological single-family house was developed and built to disturb the processes of nature during its life cycle as little as possible, e.g. to exist in harmony with nature. The house should be a simple and cheap basic house for everyone, still having good architectural quality and providing occupants good quality and flexible living spaces.

The Marjala house [5] is built largely of wood and wood products. Other keywords are local products, simple technical solutions, repetition of same details and components, thus decreasing the number of different components. The inner surfaces are coated with so called ecological materials from nature, such as wall paper, paintings and waxes. The outer paints are cooked on site or made of skimmed milk as a base material. It gets its energy for heating and hot water from firewood and sun. There's one stove in the house and 10 m^2 solar heating panels on the roof. Heat from firewood and sun is collected and stored in a 1.500 liter hot water tank. Standby heating is provided by a 6 kW electric heater at the bottom of the tank.

The heating energy of the Marjala house is 42-50 % of that of eight reference houses. It is supplied with an owner's manual and service instructions for the next 50 years.

Another sustainable building example is an energy-conscious dwelling. The purpose there was to find out the actual influence of structural and technical systems on construction costs and comfortable dwelling when ecological alternatives are favored. The goal was a 30 per cent reduction of annual heating energy without significantly increasing construction costs. First, performance and costs of various exterior walls and windows were calculated. A trade-off comparison between a better thermal insulation of exterior walls and windows and, on the other hand, building costs and dwelling comfort was performed.

The results indicated the fact that a better insulation gives an opportunity of using floor and air heating based on low temperature technique. An experimental apartment was constructed, based on the results obtained. This was a block of flats containing 15 apartments in Helsinki. Eleven of the apartments were equipped with air heating and four with floor heating. All of them had individual ventilation and a heat recovery unit. In humid rooms there was an additional floor heating facility (integrated in the heating system).

Room temperatures and dwelling comfort were studied in two air heated and two floor heated apartments. Energy consumption was measured from November 1995 to October 1996. The results were reassuring: The energy consumption of the heating system was 59,1 % lower than in the reference building and 30,4 % lower than the original goal. The energy consumption (hot water included) of the experimental building was 49,7 % lower than in the reference building. The annual temperature efficiency of the heat recovery systems was 42,7 % in air heated apartments and 40,8 % in floor heated apartments.

Due to the good indoor climate the apartments are suitable for allergic persons. Some additional research on air conditioning and water systems is still needed.

4.2 Criteria for ecological neighbourhood

The City of Helsinki and the Eco-Community Project organized a design competition for experimental building in a rural area including ecologically sensitive and valuable protected waterfronts at Viikki near the centre of Helsinki [6]. The competition aimed to save nature and natural resources, to have a high quality with regards to their architecture and functionality of the dwellings, and to be feasible to construct. The competition also was a means for a search for solutions which follow the principles of sustainable development and which could be more generally applicable. A group of building consultants devised a tool for the ecological assessment of building plans.

Viikki's ecological criteria for ecological construction [7] is a method that defines minimum ecological levels for building and estimates the ecological degree of various development projects. Minimum ecological levels for building have been dimensioned to enable their implementation in residential construction to be carried out at a reasonable additional cost. The fulfilling of ecological criteria will also achieve cost savings during the use period. These criteria, whose purpose is to serve as a guide for design and implementation, shall be appended to regulations concerning building practices at city cites.

In Viikki, increasingly ecologically conscious building will progress as a four-step process: a minimum level of ecological criteria applied to all projects, supportive PIMWAG points for significant trial projects with a high expectation value, experimental image buildings representing radical ecological construction, and follow-up studies for mapping information about projects under construction. Examples of the required minimum levels are as follows (difference from reference building):

• CO_2	3.200 kg/grm^2, 50 years	**(- 20 %)**
• waste water	125 l/resident/day	**(- 22 %)**
• construction site waste from building	18 kg/grm^2	(- 10%)
• waste produced by residents	160 kg/residence/year	(- **20** %).

4.3 Business based on waste recycling

The annual steel production in the world equals ca. 700 million tons. At the same time the steel industry produces approximately 400 million tons of by-products, solid residues and sludge. In addition to the reduction of waste and emissions, the effort towards a waste-free steel industry has created business activities based on the useful application of by-products. Recycling in the steel industry means primarily either returning by-products into metallurgical processes or utilization of the by-products elsewhere.

In Finland there are two steelworks based on blast furnace hot metal production and two steelworks with electric arc furnace technology. The integrated steelworks in Raahe and Koverhar produced 2.6 million tons of steel, and 0.8 million tons of blast furnace and steel slag. Besides this, approximately 0.15 million tons of dust and mill scale were formed as by-products of the process. In Tornio approximately 0.3 million tons of Ferro chromium slag and 0.16 million tons of electric arc furnace slag were formed.

SKJ Companies, a subsidiary of the Finnish steel group, Rautaruukki Oy, is responsible for utilizing the by-products of steel industry. Activities cover the whole range of the by-product business from by-product treatment to product development, marketing and export. SKJ has developed into products and is marketing approximately 90 % of the above mentioned by-products of Finnish steel industry totaling about 1.4 million tons. Slag, that is the largest product group by volume, is marketed to road construction, agriculture and the building materials industry. SKJ companies have activities in the fields of by-product treatment, product development and technology know-how. With regard to the technology know-how SKJ also has activities within export. The primary export countries have been Russia and East European countries.

4.4 Sustainable electric and district heating energy plant

The new energy plant of Helsinki City uses natural gas as its fuel and produces a nominal electric power of 450 MW. The fuel is fossil, but offers the advantage of practically no particle and sulfur emissions. The NO, emissions are low: for NO_2 only 35 mg /MJ of fuel. In comparison, modern coal-fueled plants emit ca. 50 mg/MJ, and 10 years ago typical emissions for coal were above 200 mg/MJ. Also carbon dioxide emissions are low, only 56 g/MJ (more than 90 g/MJ for coal).

The power plant produces both electric energy and district heating energy. The electric energy is produced in two stages by gas and steam turbines. The remaining useful energy (about half of the yield) is then available for district heating. The amount of unused heat (e.g. outside the heating period) is cooled by seawater. When all available energy is used the total efficiency of the plant is about 90 per cent. About 50 % of district heat is used in the densely built area of Helsinki. The heat from the energy plant is lead outside of this area, to North and East parts of the city, via a new 20 km long district heat tunnel (an investment of ca. 500 million FIM). About 90 % of the building volume in Helsinki is covered by district heating.

5 Considerations for the future

One of the concrete measures towards sustainable construction is the development and implementation of environmental management systems. The basic idea there is continuous environmental improvement of activities with the help of measurable targets. By means of an environmental management system, it is also possible to benchmark the environmental level of an enterprise to others. The building up of the environmental management systems is increasing in Finland.

Consequences of sustainable development on the construction industry by the year 2010 were studied in a CIBW82 project Sustainable development and the Future of Construction [8],[9]. That project resulted in the following recommendations to the Finnish building sector [2]:

<u>Building owners</u>:

- to set concrete environmental demands to the parties involved in the design process, as well as to the final product, during the initial design phase
- to set concrete goals regarding building maintenance that are based on environmentally friendly methods and include these goals in, for example, the building maintenance agreements

- assure of the productivity of one's own business by emphasizing environmental issues, quality and preservation of property values.

Building users:

- to act as a demanding customer when selecting spaces and considering the environmental qualities of the building over it's life span as one selection criteria
- to see the environmental issues as one aspect of comfort and consequently as one factor that affects the productivity of the use of the spaces
- to develop one's own activities to be more environmentally friendly in the occupied building.

Clients:

- to inform and analyze the owner's environmental demands regarding the construction project, as well as make sure they are adhered to
- to select the parties involved in the building project based on their expertise on environmental issues
- make sure that environmental goals are part of the owner's demands and implementation plans and, if needed, set them together with the owner.

Designers:

- to consider the environmental qualities of construction materials as a starting point of the design and to develop design solutions from the point of view of environmental goals of the final product
- (one can also set goals, even if the owner is not yet doing it)
- to develop the design process together with other professionals in order to achieve the optimal situation
- to develop methods and tools which will enable the designers to control not just the statics and cost but many other variables, such as life span and maintenance intervals, pollutants and health factors, heating and moisture technology etc.

Manufacturers of building products:

- to see the life cycle considerations (environmental impact, life span) as the basis of product development
- to explain in the product information the environmental qualities based on life cycle analysis, together with information regarding use and conditions of use, recycling and – and bear responsibility of that information
- to minimize actively the environmental harms of one's own production processes.

Contractors:

- to see environmental consciousness as a factor of competitiveness and to develop one's own services to be environmentally sound
- to reduce the environmental impact of one's own business processes regarding, for example site operations, logistics and material selections
- to require readiness from the other parties (sub-contractors, material and product suppliers) to work in cooperation towards environmentally sound goals.

Building maintenance organizations:

- to see environmental consciousness as a factor of competitiveness and to develop one's own services to be environmentally sound
- to correct one's own processes so that they are based on sound environmental thinking, show initiative and give feedback to the building owners regarding environmental issues

- to expect cooperation from suppliers and partners regarding environmental issues.

Officials:

- to confirm the creation and existence of mechanisms that lead to life cycle thinking
- to consider environmentally sound construction as one criteria in all building
- to use appropriate guidance (regulations, supervision and sanctions) in order to achieve environmental goals.

Researchers:

- to produce, together with other parties in the construction business, environmental qualities for entire buildings and building parts as well as methods and means to calculate them, to be used by owners, builders, designers and contractors
- to aim in one's own activities to introduce life cycle thinking as the guiding principle of design and construction process and actively implement research results in, for example, experimental construction projects
- to produce research based information to contribute to the ethical discussion on environmentally sound construction.

6 References

1. VTT Building Technology (1997) *Well-being through construction in Finland,* Vammalan kirjapaino, Vammala, Finland.

2. Huovila, P. (1997) *Sustainable Construction in Finland in 2010,* National CIBW82 Project report, VTT Building Technology 1.11.1997, Espoo, Finland.

3. Tekes (1996) *Environmental Technology in Construction,* Brochure, Töölön kirj apaino, Helsinki, Finland.

4. URL http://www.tekes.fi/english/programm/.

5. Leppänen, P. (1995) *The Marjala House; an ecological single-family house in Liperi*, Project report, VTT Building Technology 3 1.10.1995, Espoo, Finland

6. Pekkarinen-Kanerva, P. (ed.) (1997) *Ecological Neighbourhood in Viikki, Helsinki; design competitions and experimental building,* Yliopistopaino, Helsinki, Finland.

7. Aaltonen, T., Gabrielsson, J., Inkinen, R., Majurinen, J., Pennanen, A., Wartiainen, K. (1998) *Viikki; Ecological Criteria for Construction,* City of Helsinki, Finland.

8. Bourdeau, L., Halliday, S., Huovila, P. and Richter, C. (1997) Sustainable Development and the Future of Construction, *Buildings and the Environment, Proceedings of the Second International Conference,* Paris, France, 9-12 June 1997. Vol 2: Environmental management, Environmental strategies. Paris, CSTB. pp. 497 - *504.*

9. Huovila, P. and Richter, C. (1997) Life cycle building design in 20 10, *Proceedings of the 11th International Conference on Engineering Design ICED* 97, Tampere, Finland, 19-2 1 August 1997. Vo12. Tampere University of Technology. pp. 635 - 643.

Education of Construction Engineers for Sustainability

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Abstract
The issue of sustainability has become more and more important as people have begun to realise that environmental and social degradation have begun to adversely affect their life styles. Sustainability implies that the condition should be capable of being maintained over the lunger term, and this means that the broader macro-economic and social perspectives must be taken and that the needs of future generations must to be accounted for. Engineers do not currently have the appropriate training for this, However, it is felt that engineers are the appropriate professionals to be undertaking assessments of sustainability. In order to give engineers of the future the appropriate training and skills it will be necessary to change and upgrade the curricula fur their degree programmes. One approach to curriculum design is to start by deciding what the required body of knowledge comprises, and to use that as the basis, Some ideas have been drawn from recent literature as to what the appropriate body of knowledge may contain.
Keywords: Body of knowledge, curriculum design, sustainability

1. Introduction

In **1992** the United Nations held a conference on Environment and Development [10]. Its objective was to address the concern that both the natural environment and the social fabric of society appeared to be in a state of accelerated deterioration. The situation had reached a point at which the quality of life of people throughout the world was being degraded and threatened. The outcome was an agreement to try to balance environmental and social issues with the economic imperatives, in order to achieve a form of development that was more sustainable.

Although a great deal of valuable work has already been done in this area, there is still a lot to do. One of the most significant problems delaying the advancement of knowledge has been a lack of consensus on what sustainability involves. Clearly mankind cannot stop using up the limited stocks of non-renewable resources, and his very existence is non-sustainable in its current form. Hence, sustainability is not about preserving the current status quo, it is concerned with the search for efficiency in the use of resources, for integrity of the environment and the ecosystems that inhabit it, and for social stability and growth. In each of these areas, the needs of future generations must be given due weight.

When the implications of sustainability are considered in the context of an industry, it is clear that there will be interfaces with other industries and implications that will require a broader perspective than has traditionally been taken.

2. The Role of the Engineer

The construction industry is inescapably linked with the problems of sustainability. On the one hand, almost without exception developmental projects have a major constructed element, and on the other, the design, construction, and maintenance of buildings have a significant impact on the environment and on natural resources, Typical buildings using traditional materials consume more resources than necessary (partly because they tend to generate a large amount of waste), and impact negatively on the environment. Often, these buildings are also expensive to operate, throughout their life cycles, in terms of energy and water consumption.

The objective of sustainability in the context of the construction industry must be to try to develop an integrated approach to building design that takes into account the diverse needs of the environment, economy and such other political and socio-cultural factors as are considered appropriate. The target will be to produce a 'Green building' design which will "promote resource conservation, including energy efficiency, renewable energy, and water conservation features; consider environmental impacts and waste minimization; create a healthy and comfortable environment; reduce operation and maintenance costs; and address issues such as historical preservation, access to public transportation and other community infrastructure systems. The entire life-cycle of the building and its components is considered, as well as the economic and environmental impact and performance." [S]

The issues involved are much more far reaching than those traditionally involved in the technical and economic analyses that investment decisions usually undergo. If projects are to be asessed in terms of their "sustainability' then clearly, firstly some sort of index has to be available by which their performance can be judged, and secondly somebody has to be capable of undertaking the task accurately and objectively.

A number of commentators have addressed themselves to the inadequacy of existing measures of 'development', and have proposed alternate "indices of sustainability'. The web site produced by Maureen Hart [5], for example, has a lot of valuable discussion and information on this issue.

A number of the parameters that are relevant to these indices and to the concept of sustainability require an understanding of engineering principles [2]. In addition, civil engineers are already required to understand the economic and financial implications of the decisions they make, as well as being able to undertake basic environmental impact assessments and elementary social cost-benefit accounting, These capabilities suggest that engineers are the ones who should be at the forefront of the 'sustainability' thrust.

This, of course, has implications for the training of engineers, and on the curriculum that is taught at universities. The basis for a properly considered curriculum is the 'body of knowledge' that is deemed necessary to practitioners of that discipline, and as yet there has been little published discussion of the 'body of knowledge' appropriate in this context.

3. A Body of Knowledge

It is clear that one very important aspect of the body of knowledge must be related to the environmental implications of sustainability. The question is, what else needs to be included? One reference point must be the agencies that have stated a position on this matter. For example the World Bank indicated that "any project proposal should be economically and financially sustainable in terms of growth, capital maintenance and efficient use of resources and investments. It must also be ecologically sustainable in maintaining ecosystem integrity and biodiversity. Finally, it must be socially sustainable in that it should promote equity, social mobility, social cohesion, participation, empowerment, cultural identity and institutional development ." [1]

From this statement it can be seen that the World Bank sees three major categories of parameters that need to be considered when sustainability is at issue – the economic, the environmental and the social. Other organisations propose that different categories should be used when assessing sustainability, a selection of these is shown in the table below (from Cole [4]). As Cole indicates, these categories can be expanded to show the criteria considered important under each assessment method. The Canadian International Development Agency (UDA) published a paper in 1991 (3) suggesting that there are five 'pillars of sustainability' – the economic, environmental, political, social and cultural – each of which needs to be addressed when developmental projects are being considered Simmons and Cumberbatch [9] subsequently added a sixth 'pillar' that of institutional sustainability to this list.

BREEAM [6] *New office building*	**BEPAC [7]** *New and existing office buildings*	**Green Builder Program [8]** *Houses*
Global Issues and Use of Resources Local Issues Indoor Issues	Ozone Layer Protection Environmental Impacts of Energy Use Indoor Environment Resource Conservation Site & Transportation	Water Energy Materials Solid Waste

If 'sustainability' is to be a part of the training for engineers then it is necessary to define a structured 'body of knowledge'. It would seem appropriate to take the work done by the various bodies mentioned here as a starting point in this exercise,

It is clear that sustainability can be addressed at two different levels, that of the project and that of the broader community. These are not separate, discrete entities, as obviously the impacts of the project will be felt at the community level However, it is equally clear that the socio-cultural impacts of projects are not considered on most projects and, for example, are not amongst the criteria used in the Green Builder Program. When 'developmental' projects for developing countries are being considered, this issue becomes important, as recognised in the CIDA paper. The impact of a project in terms of its social and cultural acceptability will make all the difference between its success and failure. The 'Third World' is littered with the remains of projects which reflect the socio-cultural arrogance of the 'First World' in ignoring the relevance of such issues.

As a starting point, the six 'pillars' or dimensions of the extended CIDA structuring of sustainability could be used to provide a first structuring of the body of knowledge. However, in practical terms the elements that are involved in the cultural and social elements of sustainability are so close as to suggest that these two dimensions could better be combined. The same logic extends to the political and the institutional dimensions. These four, regrouped dimensions can be used to structure the elements that are essential parts of a possible curriculum for each.

Economic Sustainability

- Introduction to economic theory
- Elements of supply and demand
- Economic Development Theory
- Time value of money
- Investment analysis
- Cost-benefit analysis
- Shadow pricing
- Economic policy choices and implications
- Supplier subsidies vs. user subsidies
- Energy cost studies
- Life cycles cost studies

Environmental sustainability

- ***Global issues***
  - Acid rain
  - Ozone depletion
  - CO_2 emissions
  - Renewable resource depletion (e.g. tree felling)
  - Non-renewable resource depletion (e.g mining)

- ***Local issues***
  - Water use/pollution
  - Air pollution
  - Noise
  - Local wind effects
  - Heat source/pollution
  - Lighting
  - Materials - the 4 "R"s - Reduce, Reuse, Recycle and Rebuy
  - Solid waste management
  - Site accessibility & transportation

- ***Indoor issues***
  - Water use & waste disposal
  - Solid waste disposal
  - Air ventilation/pollution
  - Noise control
  - Heating/cooling (solar etc)
  - Insulation
  - Building envelope design
  - Building operating sensors/controls
  - Lighting/shading

Social and cultural issues

Maureen Hart's book "Guide to Sustainable Community Indicators" and her web site [5] argue that "In a sustainable society, people are connected to other people, care for others, respect the rights and feelings of others, and enjoy the diversities of multiculturalism. The subcategories of society are related to these issues and include:

Abuse - Number of people, young and old, who are mistreated and the steps taken to prevent these types of problems

Children - How well children are supported and cared for emotionally and financially

Connectedness - Extent to which people feel like they belong in their community

Culture - Availability and use of museums, libraries, theater and other cultural events by all segments of the community

Diversity - Extent to which differences within the community are not only accepted but also encouraged and celebrated

Pregnancy and birth **-** Rate at which children under **18** or unmarried women give birth to children; a negative indicator
Volunteerism **-** Willingness of the members of the community to participate in making the community a better place to live

The emphasis of society indicators of sustainable community is on improving the lives of people, not through more money or more bureaucracy but through people caring for other people."

Political and institutional issues

Again Maureen Hart [5] suggests that A sustainable community is one that will have high rates of participation by all residents and an efficient, well-managed local government. The subcategories for government indicators include:
Diversity **-** Balanced ethnic, racial, and gender representation at all levels
Leadership - Effective leadership
Participation **-** Active participation from all members of the community
Services - Well run, well used public services

The emphasis of the government indicators of sustainability is on the effectiveness of government agencies and the voluntary and active participation of the citizens."

4. Conclusions

There is increasing need for society and its representatives to become more attuned to the concerns of sustainability. In practice this will mean that professionals like engineers will have to start taking into account issues that they have not bothered with before now, It will also call for them to revise their approaches to project assessment. The needs for sensitivity to these issues will cause engineers and educators to reconsider the content **of** the curricula for degree programmes. One approach to redesigning curricula is to start from what is considered to be the essential 'body of knowledge' of that aspect of the discipline. Thus it is useful to consider what the appropriate body of knowledge may contain, The dimensions, parameters, elements and criteria mentioned here constitute a suggested starting point for developing an appropriate body of knowledge for sustainable development.

5. References

1. Allahar, Haven, **1997,** "Linking Human Needs", article in Trinidad **&** Tobago Express, 3/11/97
2. Centre of Excellence for Sustainable Development, http://www.sustainable.doe.gov/index.htm
3. CIDA **(199** *I) Sustainable Development Discussion Paper,* **Canadian Industrial** Development Agency
4. Cole, R. J., Prioritizing environmental criteria in building design and assessment, in Brandon, P. S., Lombardi, P.L. and Bentivegna, V. **(1997)** *Evaluation of the Built Environment for Sustainability*, E & FN Spon, London, pp. **183 – 199**

5. Hart, Maureen, http://www. subjectmatters. com/indicators/HTMLSrc/Society. html, and http://www. subjectmatters. com/indicators/HTMLSrc/Government. htm
6. Prior, J. (Ed.) (1993) Building Research Establishment Environmental Assessment Method, (BREEAM) Version 1/93, New Offices, BRE Report
7. Cole, R.J., Rousseau, D., and Theaker, I.T. **(1993)** Building Environmental Performance Assessment Criteria: version 1 – Office Buildings, The BEPAC Foundation, Vancouver,
8. Doxsey, W.L. (1994) The City of Austin Green Builder Program, US Green Building Conference – **1994,** NIST Special Publication #863, Ed. A.H. Fanney et al., US Department of Commerce, Technology Administration, 1994, pp **21-3** 1. See also information on the US government's 'green building' program at web site, http://www. sustainable. doe.gov/index. htm
9. Simmons, David A. and Cumberbatch, Janice A. (1993) *The South-East* Peninsular *Development Project on St. Kitts-Nevis,* Caribbean Conservation Association, Barbados
10. WCED (1987) *Our* Common *Future,* The World Commission on Environment and Development

The Concept and Context of Sustainable Development in the Caribbean

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Abstract

The concept of sustainability in the context of development is problematic, because they tend to be driven by different imperatives, Sustainability seeks the long-term continuation of a process or state, whilst development seeks change and improvement. Although not necessarily in conflict, in practice these two objectives do tend to pull in opposite directions.

In the setting of a developing country the process of development is usually dependent on the exploitation of natural resources. This sets the requirements of sustainability and development more directly at odds. Unfortunately, the costs of natural resource depletion are rarely accounted against a project's economic benefits, so environmental degradation is consistently undervalued. The trade-off between the use of resources for the benefit of today's pour and concern for the interests of future generations, is also one that is very difficult to make.

In addition, it is not just a question of balancing the demands of economy and the environment. Development only has meaning within the context of a society, and for a society to be sustainable a number of socio-cultural needs must be satisfied.

These broader issues of sustainable development need to be understood, and their implications also built into benefit cost analyses.

Keywords: Caribbean, feasibility studies, sustainable development, pillars of sustainability

Introduction

Most governments have an understandable objective of trying to improve the economic and material well being of the people they serve. This political imperative has traditionally been met by 'development' initiatives, which measure relative 'development' largely in terms of economic parameters.

In addition, these initiatives tend to adopt a "copy-cat' approach, in that newly emerging economies are expected to follow the same route to development as the mature industrialised countries. Unfortunately, the interests of the environment and development tend to be opposed, and it is the environment that has had to give way. The conflict and the compromising of the environment have been so profound that efforts have had to be made internationally to try to improve the situation.

The purpose of these efforts has not been to stop development, but to find ways to redirect or redefine development in such a way that the environment can be protected too. For example, in **1987** the World Commission on Environment and Development sought to define development in terms which would allow it "... to meet the needs of the present without compromising the ability to meet those of the future" [4]. The clear objective of "development in this light is that it should be 'sustainable'. Development implies improvement, or 'bringing to a more advanced state'. Sustainable implies 'capable of being continued without decreasing'

In the developing world, there are very close links between economic growth and the environment, because a large percentage of development initiatives exploit natural resources. As a result, 'sustainable development' increasingly means achieving economic growth without damaging the environment, Because of the limits on the levels of production and consumption that can be borne by the environment, the concept of sustainable development involves sensible limitation on the exploitation, of natural resources especially those that are non-renewable.

The concept of sustainable development is, of course, anthropocentric in that its objective is to provide long term support for human habitation. But man is a social animal, so the issue is not just life support, but also the long-term preservation of 'civilisation'. Thus sustainability must take a broader prospect than that of economics and environment.

A **1991** discussion paper put out by the Canadian International Development Agency [1] indicated that sustainable development should involve sustainability in five dimensions, the economic, environmental, social, cultural and political, dimensions. These dimensions were called 'the five pillars of sustainable development', Subsequently, Simmons and Cumberbatch [3] suggested that the CIDA paper had ignored a key sixth pillar, that of institutional sustainability. The issues involved with each are discussed below.

Economic Sustainability

The interests of economy in development projects have been well served by investment analysis and cost-benefit analysis over the years. However, these approaches have their shortcomings when it comes to sustainability issues. There are two specific problems, one is the failure of the measures to take account of the depletion of natural “capital’, and the other is their inability to distinguish between a disaster and a windfall.

In most analyses the stock of a natural resource is treated as a ‘free’ consumable. Exploiting natural resources, without any need to acknowledge that the resource base has been depleted can enhance current economic performance. As a result, the rights of future generations are ignored.

Even where a more enlightened approach is attempted, the analysis of projects tends to use discount rates that are close to the social opportunity cost of capital - which tends in the Caribbean to be greater than 10%. Such discount rates tend very heavily to favour returns in the short-term. Projects that have relatively high current costs, and benefits that are enjoyed some significant time in the future, are heavily disadvantaged. This means that environmentally oriented projects, like those associated with reafforestation, are almost impossible to justify on economic grounds. Clearly this is inappropriate when sustainability becomes important.

The second problem with current economic measures is that an ecological disaster, like an oil spill, only shows up in national accounts as an increase in economic activity. In other words, it has a positive economic effect, without its negative environmental consequences being accounted. Even the outbreak of a disease can appear economically favourable in that it enhances medical activity without its negative effects necessarily showing up in the accounts anywhere.

These shortcomings are not insurmountable. The challenge is to achieve economic sustainability whilst ensuring that natural resources are used efficiently and with due recognition of the rights of future generations. Also, where there are negative environmental, social or cultural consequences, these should be fully accounted as costs, and set against the benefits of the project or activity

Environmental sustainability

The state of the environment is a matter of growing current concern, It is not a philanthropic concern, It is a concern based on the observation that degradation of the environment is already affecting the quality of life of people throughout the world. Mistakes of the past are revisiting the present with unanticipated and unacceptable consequences. Thus, protection of the environment must be factored into the decision making process.

There are three basic services that the environment provides. The first is that it is the source of the natural resources (like Jamaican bauxite, Trinidad oil or Barbados’ beaches) that are the raw materials used as the inputs to human activities. Secondly, it serves as a ‘sink’ which absorbs, and often recycles, the waste products of human activity. The third service the environment provides is in a range of virtually irreplaceable functions that are often life sustaining (like the stratospheric ozone layer which filters the ultraviolet rays that are harmful to humans).

The recognition that damage to the environmental was reaching a level at which it was becoming unable to sustain these services has led to a reappraisal of how to integrate the costs associated with environmental degradation into conventional economic decision-making. The basic approach has been to value environmental assets and to put a cost on their degradation that can be accounted in project level cost-benefit analyses. There are still problems associated with the valuation of public environmental assets (like a reef, for example) and with appropriate discount rates, but at least a start has been made in the recognition of environmental costs within projects.

Once environmental economics become accountable at the national level it is likely that effective systems of management will be introduced. These systems would be directed towards trying to use scarce resources in a more sustainable way, assisting nature by attempting to rehabilitate and restore damaged or degraded ecosystems and natural resources, and by enhancing the productive capacity of 'natural' ecosystems,

Social Sustainability

Large sectors of society, particularly in the 'developing' world, have failed to benefit from conventional development initiatives. The large and growing populations of poor have become relatively worse off, as the anticipated "trickle-down" of benefits has failed to materialise. This has led some commentators to demand that efforts should be made to directly improve income distribution [2]. The concept of 'equity' has become an issue in sustainability, as, clearly, a social situation that is perceived to be inequitable will not be sustainable in the long term.

The principal goal of 'social sustainability' is improvement in the standard of living of all members of a society. In a developing country, this will be tempered by the need to bias the improvement towards the needs of the poorer members of the society. This requires that opportunities for human development should be available to all, and this calls for special attention to be paid to:

- improving the distribution of income;
- striving for equity regardless of gender or race;
- removing unfair barriers to land ownership, employment and education
- ensuring adequate access for all to the social infrastructure (e.g. schools, hospitals, housing, and community centres).

Social cost-benefit analysis has attempted to incorporate social equity concerns by "weighting' the benefits (and costs) of development projects according to the income level of the beneficiaries, However, this is not a satisfactory process, because it is prone to subjective distortion, and it is more normal to keep the economic and social analyses separate, but with the economic objectives being moderated by the social objectives.

Cultural Sustainability

Culture can be defined as the self-identity and creativity of a people. It is the sum of the beliefs and customs, traditions and ways of expression, it is constantly under pressure but also it is always evolving as a society develops and has intercourse with the rest of the world.

Caribbean culture has certain characteristics. It is comparatively young, very diverse and draws its heritage from the various Amerindian, European, African, and Asian ethnic groups that make up the population. Its immaturity and the insecurities of many of its people make it particularly vulnerable to outside influences.

Cultural sustainability rests upon the recognition of these threats and requires that the arts and other aspects of culture (language, music, dress, and folklore) are not degraded, diminished or crowded-uut by foreign influences. Ideally, at the end of a development initiative the self-esteem of the people, and their culture, should be intact [3].

Political Sustainability

In the broadest terms, political sustainability involves the absence of political conflict (civil and guerrilla warfare, excessive criminal activity), democratic governance and a respect for human rights, Lack of overt conflict does not mean that the people are satisfied with their government, as there may be a very strong desire for more accountability, and for greater efficiency in the public service and in the use of public funds. Political sustainability is more than free and open elections. It means freedom of speech and expression, respect for human rights, the pursuit and practice of 'good government', the absence of corrupt government officials, honest and competent public administrators, and efficient public services.

Although the rhetoric may suggest that there are very wide gaps between the political parties, this is not really the case in the Caribbean. Most of the territories have systems of governance that are politically sustainable, despite the occasional hiccups like the attempted coups in Grenada (1983) and Trinidad (1990) and the post-election unrest in Guyana currently (January 1998).

Institutional Sustainability

The term 'institutional sustainability' refers to the procedures that are established to determine and execute government policies. Institutional sustainability is analysed on the basis of a capacity for policy making, for policy implementation, and for monitoring and enforcement.

Caribbean countries have largely followed the Westminster system of government, under which policy is formulated at the top and handed down. Policy making is initiated more by the 'collective wisdom' of the ruling party or the dictates of a Prime Minister than in response to public expressions of concern Economic policy which requires 'development assistance' from international agencies is influenced by the policy measures that the donor agency believes are in the best interests of the country, or that satisfy other agendas of the agency.

The policy making process itself has many defects and shortcomings, but these problems are compounded by the ineffectiveness of implementation. One reason is the inadequacy of the legal systems to respond appropriately with adequate laws and regulations. This is particularly the case with environmental legislation, which in the Caribbean, is by-and-large both outdated and redundant. The situation is improving, however, with the recent creation in Trinidad, for example, of an Environmental Management Agency charged with coordinating and rationalising public sector environmental activities.

In general terms, institutional sustainability involves:

- the articulation of national policy;
- the creation and encouragement of inter-sectoral and cross-sectoral coordination among agencies whose policy/development actions interact;
- the formulation or strengthening and enforcement of appropriate legislation;
- the integration of responsibilities;
- the creation of adequate data bases to support planning and management processes; and
- the provision of relevant training for staff.

Interaction

These six "pillars' of sustainability are inter-connected and the attainment of sustainability in any one is closely linked to activities in the other five. This becomes clear when the development process is examined, because it is rare when issues arise that they do not cross over two or more boundaries. For example, there is little doubt that economic activity can have a negative impact on the environment and likewise, that environmental damage will have negative economic consequences, The challenge is to promote economic activity in such a way that the level of environmental quality remains intact or that there are appropriate compensations for its loss, and that any other negative impacts that the initiatives have on the socio-politico-cultural complex are compensated for.

Although a framework is beginning to emerge for addressing the issues surrounding the different 'pillars' of sustainability, the problems of practical implementation still remain. Although there is growing need for methods of evaluating the costs and benefits of initiatives in each of the areas defined by the 'pillars the problems will not easily be overcome, at least in part because they are both cross-disciplinary and multi-disciplinary.

The best model for addressing these issues that exists currently is that of the feasibility study that is used widely in the construction industry. An effective feasibility study for a major project nowadays must include a benefit-cost analysis and an environmental impact analysis. It will also usually address issues like marketing, manpower planning, management structure, risk and sensitivity issues, foreign exchange issues and any major political, financial, social or other susceptibilities of the project to its environment. Many of these issues are only touched upon, but they do lead very directly into the requirements of the 'pillars' of sustainability that have been discussed. The emphasis of the feasability study currently, however, is more one of ensuring that a project is technically possible and economically justifiable (usually in present value terms), than that it is itself sustainable in the longer term, or contributes towards broader national sustainability. For public sector projects it should not be difficult to change this emphasis. The problems involve the practical estimation of value of damage to the environment and (even more so) to socio-cultural attributes and the implementation of procedures that can help avoid or alleviate such damage.

Summary & Conclusion

The countries of the Caribbean area can broadly be considered to be developing economically. As a result they are undergoing significant changes in terms of infrastructure, industrial structure, and economic growth. Whilst these changes have their positive aspect, they also bring with them potential problems. The problems can take the form of environmental degradation, or may by more related to unwelcome socio-cultural changes. The objective of 'sustainable development' is to try to anticipate unfavourable changes and to moderate the project parameters to try to avoid these unwanted consequences.

The construction industry is actively involved in almost all development projects. As a result, the traditional construction industry feasibility study appears to be the appropriate context for an assessment of sustainability in all its various dimensions. The process of assessing sustainability has not yet been properly developed, and it is an area in which active work is needed.

References

1. CIDA (199 1) *Sustainable Development Discussion Paper,* Canadian Industrial Development Agency.
2. Pantin, Dennis & Mohammed, Asad (1994) *The Dundonald Hill Estate In Urban Port Of Spain Trinidad And Tobago,* Caribbean Conservation Association, Barbados
3. Simmons, David A. & Cumberbatch, Janice A. (1993) *The South-East Peninsular Development Project on St. Kitts-Nevis,* Caribbean Conservation Association, Barbados
4. WCED (1987) *Our Common Future,* The World Commission on Environment and Development

Life cycle assessment of building-components - concentration on the phase of use

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Abstract

In order to analyze and assess components according to the standard of the LCA (life cycle assessment), at the beginning of the investigation, the necessary boundary settings must be defined and described. These settings should be carefully considered between the product to be investigated and the future user (in this example the planner). For this purpose, it is required to try to get to the bottom of specific features and characteristics of components and to find out what kind of analyzing and assessment criteria are of interest for the planner or to what phases of life cycle of the components he is paying special attention.

In the LCA, there are various evaluations which, with regard to their contents and principles of consideration can be „reduced“ to two basic types of assessment. These are the product-related LCA and the company-related LCA. Because of the long life expectation of components, their assessment is a combination of product statement and operating statement.

For low-cost building and building activities with ecological awareness, not only the decrease of non-recurring expenditures (for the product) are of interest but it is necessary too, to influence and reduce the current expenditures. Thus, for the planner the company-related LCA of components is of greater importance. The company-related LCA should take into account important functional and economic aspects, which are of interest for the planner. Settings worked out in the design can be shown and assessed in the planning stage with regard to their usefulness and their environmental effects (testing of design qualities).

In this context, for the planner an LCA that emphazises the operating statement of the phase of use during the life of components could possibly be of greater importance than a merely produkt LCA.

Preliminary remarks

Building processes are linked with considerable transformations of material and energy. Proceeding from the demand to economize nature and showing environmental consciousness, persons involved in building processes are expected to cut down these transformations of material and energy as well as the resulting impacts on the environment. So, in the field of building efforts are made to influence the ecological impacts of building products and building processes. Increasingly, technologies and methods are searched for which can illustrate and assess the environmental impacts of building products and the impacts caused by their utilization. In this context, the LCA moves into the centre of discussion.

1. LCA - stage of development

LCA are tools for the analysis and assessment of environmental impacts. The phases of an LCA study are goal definition and scoping, inventory analyses, and impact assessment. Within impact assessment, there are three elements: classification, characterization, and valuation. They are to investigate, demonstrate and assess products „from-cradle-to-grave" with regard to their environmental impacts.

Within the scope of international standardization, in recent years a standard model of LCA (EN IS0 14040 - 14043) was worked out. As the LCA is related to interests and subjects and, the settings required at the beginning of each balance considerably depend on the product to be investigated and on the user (see Figure 1, next page), international standardization does not go beyond general settings and guidelines: the EN IS0 14040 *„specifies the general framework, principles and requirements for conducting and reporting life cycle assessment studies. This International Standard does not describe the life cycle assessment technique in detail. " [5].* Therefore, more detailed hints and settings (balance unit, balance limits: in factual, spatial and temporal aspect) must be elaborated by experts on the basis of the standard for various products and related to the user.

In order to assess building components according to the standard of LCA, the settings required for the investigation must be defined and described. For this purpose, it is necessary to try to get to the bottom of the specific features and characteristics of components and to find out what criteria of analysis and assessment are of interest for the planner or to what phases of life cycle of the components he pays special attention.

2. LCA - different approaches

The different approaches are similar in principle, however, differ in the mode of consideration or directions of consideration (upstream, downstream), in the necessary boundaries (scope and boundaries of considerations) and in the modes of calculation (contents, principles). The differences between the various LCA mainly arise from different subjects of consideration. In this context, product-related, process-related, company-related, business related or trade- related balancings should be mentioned. Within the scope of the ecological balancing of components, the most appropriate valuation among those possible simplifications and balancings should be found out.

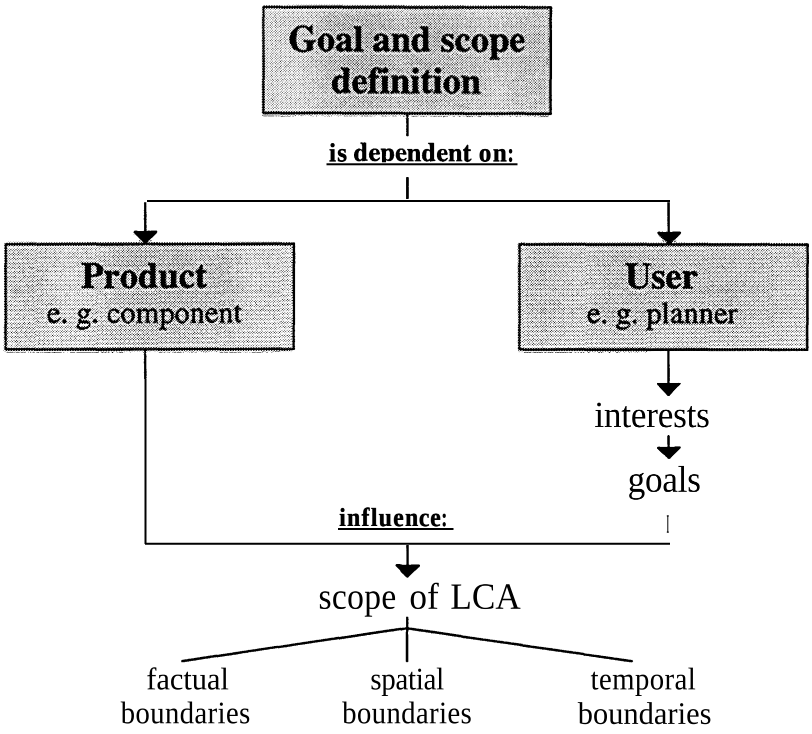

Figure 1: Dependences of „Goal and scope definition"

Though there are various and different approaches of simplifications and valuations when investigating them in greater detail, it turns out that with regard to their contents of consideration they can be „reduced" to two basic types of balancings, i.e. the product-related and the company-related LCA.

In the **LCA of a consumer product,** physical products are considered which were generated by a different number of steps of production, they can be seen as a „ready-made piece". All the relevant quantities of material and energy are calculated for a definite quantity of the respective product in the sense of a **„one piece consideration".** As the considerations refer to the total product's life, no special temporal boundaries result. A spatial boundary is scarcely possible because the product moves during its life cycle and therefore no definite site is given.

In the **LCA of companies** processes of production are investigated where one or several physical products are made. It is not the product which is in the centre of considerations, but the entirety of the processes of production of an economically independent functional and organizational unit (enterprise). To assess its environmental impacts, all the relevant quantities of material and energy are investigated, distinguished in environmental categories for a definite period of time. In general, the period of time refers to a calendar year and is repeatable in regular intervals. So the balancing is equal to a **„periodical calculation".** Due to physically given limits of enterprises or companies, a spatial delimitation can be defined easier. The relevant data are measured and investigated for an economic functional unit or organizational unit at a definite site.

To answer the question asked at the beginning, to what extent LCA can be used to illustrate and to assess the environmental impacts of components and of their use, it should now be found out what type of LCA should be used and what product-related and user-oriented specialties should be taken into account.

As shown in Figure 2 by a model, the life of components is subdivided into various phases of the life cycle.

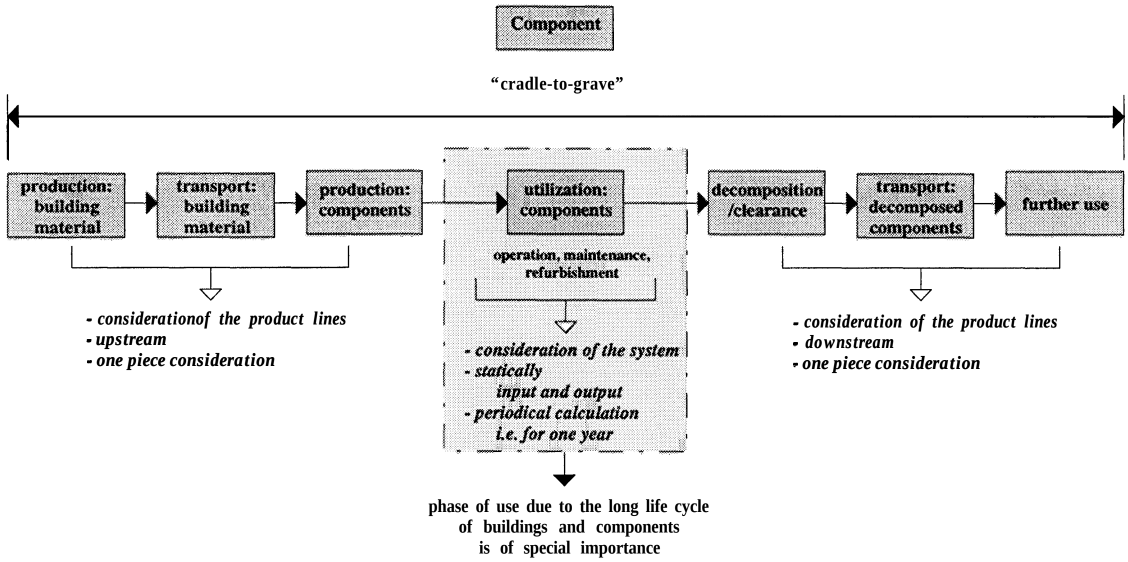

Figure 2: Various modes of consideration within the product line ,,component“

Starting from the ,,production of the building material“ up to the ,,production of the components“, the building product is considered in the sense of one piece along his product line ,,upstream“. In the phase of ,,utilization of the components“ including maintenance and repair, material and energy flows arising from the production of the components are transferred into a "stock of material and energy“. Material and energy flows which arise from the production of the components are terminated, however, flows arising from the utilization of the components occur. It is necessary to heat the buildings, to clean the buildings and to preserve and refurbish the buildings in regular intervals. Depending on the good or poor quality of the building components of the total system ,,building“ and on the functioning ,,when acting together“ (basement, floors, walls, ceilings, roof, elements which close openings), the necessary expenses will be higher or lower. Within the operating phase, the material and energy flows of the building components which arise from the utilization are in the centre of considerations. Inputs and outputs coming up are investigated in the sense of an input-output-calculation and can be periodically (e.g. annually) determined (periodical calculation).

After the ,,utilization of the component“ is finished, the building product - from decomposition to clearance - is considered again as one piece along his product line ,,downstream“ in the sense of a consideration of one piece.

3. LCA for “building components”

As a result, the assessment should always be a combination of product- and company-related. Because of the long life of the components and the total system “building” where they are integrated, the operational statement gains in significance. Here, the settings of design and production of components by the planner are shown and elucidated with regard to their long-term effects on service life. So differences in materials, combinations of building materials and principles of construction have strong influence on various aspects of the usephase, whether

- they are convenient for repair of components (e.g. uncomplicated mounting and demounting of outdated or damaged layers and parts without damaging otherlayers or parts of the components),

- they provide stability and support a long life of the components (e.g. combination of layers and parts of similar stability and durability in order to avoid mounting and demounting in the meantime and thus, additional costs),

- they offer weather resistance, protection from parasites, cleaning, chemical resistance (e.g. mounting of components which are frequently to be cleaned at places where they are accessible without great efforts),

- they allow the realization of technically perfect individual solutions (e. g. avoidance of building faults and thermal bridges),

- and disposition possibilities (connections, design) in length, width and height: with regard to the ground plan, the storeys and the sizes of rooms.

Describing these aspects, conclusions may be drawn with regard to necessary and additional measures of preservation, maintenance and refurbishment. In the phase of use they can be reflected by the expenditures concerned and give the planner indications of potential corrections to planning and implementation. In addition to the presentation of expenditures, effects can be shown which characterize and influence the appreciation of the components. So for example, different modes of construction - with profit or loss - will have an effect on the size of the living-space.

Analyzing the product “component” and the research results on the "LCA interest” and “information needs” of planners [1], the following becomes clear:

- as a result of the long useful life and service life of components and of the fact, that the functioning of a component in the phase of use can be compared with the operating expenditure of the higher system “building”, the LCA balance to be carried out is always a combination of a product-related and process-related balancing (assessment of the single and regular expenditure),

- looking at the total product’s life, a building with environmental awareness does not only mean the reduction of single expenditure (for the product) but influencing and decreasing the regular expenditure (for operation). Hence, for the planner the analysis following the principle of the company-related balancing should become the focus of attention,

- the decisiones made by the planner in the designing phase about materials and the production of components in the long run will show their effects in the phase of use. These can be illustrated and assessed within the company-related balancing (testing of designing qualities). Then the planner should incorporate into the balance such functional and economic aspects which have influence on the ecological impacts (extended operation statement).

It is scarcely possible to set up a complete and universally applicable ecological balance for components showing and assessing all the relevant environmental impacts "from the cradle-to-the-grave". As the components have to come up to functions (services), for the planner it is of interest to know the effects of coming up to these functions during the "operational phase" and where within the planning and production there will be possibilities to influence these impacts in advance. In this respect, an extended operation statement for the analysis of the useful life service of components would be of possibly greater importance than a pure output statement.

References

1. Blum, A.; Deilmann, ***C., Baustoffe - Umwelt - Gesundheit: Informationsbedürfnisse bei Planern und Architekten,*** IÖR-Texte 117, Dresden, 1997

2. Corino, ***C., Ökobilanzen: Entwurf und Beurteilung einer allgemeinen Regelung,*** Umweltrechtliche Studien, Band 19, Werner-Verlag, Dusseldorf, 1995

3. De Man, R. (Leiden/Niederlande), ***Erfassung von Stoffströmen aus naturwissenschaftlicher und wirtschaftswissenschaftlicher Sicht - Akteure, Entscheidungen und Informationen im Stoffstrommanagement***, in: Enquete-Kommission "Schutz des Menschen und der Umwelt" des Deutschen Bundestages (Hrsg.), Studienprogramm - Umweltvertragliches Stoffstrommanagement, Band 1 - Konzepte, Economica-Verlag, Bonn, 1995

4. Engelfried, J., ***Dienstleistung als methodische Grundlage von Produktlinienuntersuchungen,*** JF Lehmanns Fachbuchhandlung GmbH, Abt. Verlag, Köln, 1994

5. EN IS0 14040 - 14043, ***Environmental management - Life cycle assessment,*** 1997

6. Rubik, F.; Teichert, V., ***Ökologische Produktpolitik. Von der Beseitigung von Stoffen und Materialien zur Riickgewinnung in Kreisläufen,*** Schäffer-Poeschel Verlag fiir Wirtschaft - Steuern - Recht GmbH, Stuttgart, 1997, S. 45 1

7. Rudolphi, A., ***Produktökobilanzen und ihre Anwendungsmöglichkeit im Baubereich,*** in: Tagungsband des Seminars "Produktbezogene Ökobilanzen V" im Rahmen der UTECH BERLIN, Berlin, 1997

8. Schmidt, M.; Häuslein, A., *Ökobilanzierung mit Computerunterstützung. Produktbilanzen und betriebliche Bilanzen mit dem Programm Umberto*, Springer-Verlag Berlin Heidelberg, 1997,232 S.

9. UBA, *Jahresbericht 1996*, Berlin, 1997

10. Wagner, B., *Vom Öko-Audit zur betrieblichen Öko-Bilanz*, S. 3-31 in: Lehmann, S.; Clausen, J. (Hrsg.), Umweltberichterstattung von Unternehmen, Schriftenreihe des IÖW 57/92, Berlin, 1992, 107 S.

The influence of the use-efficiency on the resource-efficiency of housing

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Abstract

Within the debate of sustainable development there is far to much emphasis on technical issues and to little concern about the use of services and patterns of consumption. The presentation will prove, that even without change in consumption patterns, the resource efficiency of housing can be improved more easierly by means of good housing management than by technical improvements and energy savings. The extention of the life periode of a building (durability, social acceptance) and use-factor per year (avoided vacancies, a better managed occupancy) might be a significant contribution to higher efficiency in the housing sector.

The author developed a calculation methode, which enables to compare benefits (in energy and mass flow) by better management with those by technical improvements of buildings. [1] The calculation methode is explained in the full lengh paper.

The following example of a calculation result can illustrate the approach in brief A flat that's used by a family over 35-40 years shows periods of higher and lower occupancy rates. The move of a 'remaining' widow(er) to a smaller flat can improve the use-efficiency of the "service-unit" by 10-20% depending on how long she (he) would otherwise have stayed alone in the flat. The contribution to savings in energy and materials by a successfull management of ocupancy will be in the given example more effective than an energy saving measure that reduces space-heating demand by 50% over the whole periode of occupancy of the building.

The calculation methode and the results open up the mind for the importance of housing management, of flexible housing market and building restoration. Whether materials, energy, capital and human labor are used efficiently can only be judged, when the object of concern is not the product (house), but the service (provision of living-space). So, the investment of a large housing estate in a good occupancy-management can save up as much natural resources as a thermal insulation campain for the housing stock.

Keywords: resource-efficiency, use-efficiency, occupancy-management, housing as service

1. Housing demand and housing provision

The concept of sustainable development asks the industrialized countries for a reduction in resource-consumption per capita. In the case of housing even a zero-growth-scenario will be difficult enough to reach. It means, that the relative savings per floor-area by energy conscious design and retrofit must outweight the absolut growth of floor area caused by a growing demand. It is therefore worth looking at both sides: the quality of the offered building products and the demand for housing.

The ressource-efficiency of products like houses or towns is far more determined by the consumption-periode than by the construction and demolition periode. Ecological orientated building research has always looked at the improvement of the efficiency per constructed floor area (material flows to construct and to run the building). It was mostly not questioned, whether the product is used adequate and efficient. But the extention of the life periode of a building (durability, social acceptance) and use-factor per year (avoided vacancies, a better managed occupancy) might be an even more significant contribution to higher efficiency than technical measures.

Todays lifestyles and types of households are characterized through a great variety. The classic average-type familiy belongs to the past. Households with one or two kids are in modern society a minority group. The individual passes along his life different phases. In each of those it is member of a different typ of household and is looking for an adequate place to live. This causes a great variety in types of demands, which are increasing accordingly to the differenciation of ways of living. It seems obvious, that only a more flexible housing market, an occupancy-management and incentives or support for people wanting to move can help to match the demand more closely.[2]

2. Calculation methode and examples

The calculation methode wants to illustrate the effects of good management in terms of energy and mass-flow, and pin-point the potentials of organizational measures which can guide the demand more resource-consciously

To begin the calculation, one has to define a dimension, which allows to compare different types of housing and households regardless of the ways of living. As a basis for comparison a service-unit of 35 m^2 per Person could be defined. (For the comparison it is unimportant whether 30 m^2 or 40m^2 are the basis of calculation. And: It is not at all the aim of the approach to deliver arguments for a limitation of individual consumption. A discussion that would head towards regulation of personal consumption would find no acceptance in democracy based countries.) The calculation orientates only on a comparison in terms of resource-efficiency between technical and organizational measures of housing provision. For a defined service unit one can then calculate the resource intensivness of construction, maintenance and other efforts. On this basis the resource-consumption of different uses of a given service-unit will be calculated.

First one multiplicates over the life-cycle of a dwelling the different occupancy-periodes in years (a) by persons (P) and the agreed service-unit-area (m^2/P) and adds them up to a total theoretical floor-area consumption. By division with the total time of the cycle one gets a floor-area-equivalent ($Wfl_{äq.}$).

$$\sum (35\ m^2/P \cdot P_{1\ldots} \cdot a, \ldots + 35\ m^2/P \cdot P_n \cdot a_n) / \sum a_1 \ldots + a_n = WFl_{äq.}\ [m^2]$$

The division of floor-area-equivalent $(Wfl_{äq})$ by floor area of the dwelling leads to the use-intensity of the dwelling (NIPWS). (Tab. 1, 2)

$$\frac{WFl_{äq} \quad [m^2]}{WFl \quad [m^2/WE]} = NIPWS \; [-/WE]$$

Household	**years**	**Persons**	**P · 35 m²**	**P · m² · a**
Couple + 2 Kids Couple + 1 Kid Couple Widow(er) Vacancy	14 2 14 10 0,25	4 3 2 1	140 105 70 35	1960 210 980 350
	40,25	100 Pa		3500
floor-area-equivalent			86,95	
use-intensity	1,087			**NIPWS**

Tab. 1: flat with 80 m² - family-cycle without move-management

Household	**years**	**Persons**	**P · 35 m²**	**P · m² · a**
Couple + 2 Kids Couple + 1 Kid Couple Widow(er) Vacancy	14 2 14	4 3 2	140 105 70	1960 210 980
	30,0	90 Pa		3150
floor-area-equivalent			105,00	
use-intensity	1,312			NIPWS

The use-intensity and the resource-efficiency per offered service-unit increases by 20 %.

Tab. 2: flat with 80 m²/WE - family-cycle with move-management

In a second step one multiplicates use-intensity with material-input for building construction, maintenance (in kg) and the energy-use (in SKE -coal- kg). The result is the specific material intensity per service-unit and year (in t/WS·a). (Tab. 3)

The data base for input is here an average over different types of construction in Germany (mostly solid, heavy-weight construction). It doesn't contain sideeffects of previous process-chains or soil movements.

The energy consumption represents the average input for space-heating, warm water and electricity in Germany. It is primary energy, including the energy that was needed to win the fuels. The data was then converted into coal equivalents (kg).

examples	kg/m²·a materials	kg/m²·a energy(2)	m²	use-factor. %	materials t	energy t	tons/ WSa
flat 100a	20,7	44,6	35	108,7	0,66	1,436	2,102
flat +20%UI	20,7	44,6	35	131,2	0,552	1,189	1,741
flat 150a	13,8	44,6	35	108,7	0,444	1,436	1,880
flat -50% sp.h.	21,2	33,4	35	108,7	0,683	1,077	1,760
flat- ecobuild	15,4	44,6	35	108,7	0,495	1,436	1,931

Abbreviations:

(2)	=	average energy consumption in german housing stock
flat 100a	=	flat with life-expectation of 100 years
flat + 20 % UI	=	same flat with increase in use-intensity by 20 %
flat 150a	=	building with life-expectation of 150 years
flat - 50 % space.h	=	reduction of energy use for sate-heating by 50 %
flat ecobuild	=	ecological building materials

Tab. 3: Comparison of different measures to improve the resource-efficiency per service taking into account the different use-factors (in tons per year and service-unit)

flat examples	kg/m²·a materials	kg/m²·a energy(1)	m²	use-factor. %	materi-als t	energy t SKE	tons/ flat
flat 100a	20,7	28,0	70	110,0	1,317	1,781	3,099
flat- 1 0%UI	20,7	28,0	70	99,0	1,463	1,979	3,442
flat -30% sp.h.	21,2	24,0	70	110,0	1,349	1,527	2,876
flat -30%-10%UI.	21,2	22,9	70	99,0	1,498	1,619	3,117

Abbreviations:

(1)	=	energy standard 1994
flat 100a	=	flat with life-expectation of 100 years
flat- 10 % UI	=	same flat with decrease in use-intensity by 10 % through vacancies
flat - 30 % space.h	=	reduction of energy use for sate-heating by 30 %
flat - 30 % -lO%UI	=	sate-heating - 30 % and Use-intensity minus 10%, taking in account, that the unoccupied flat is only "passiv" (by neighbours) temperated

Tab. 4: Comparison of the effect of vacancies and of energy-saving measures in terms of the resource-efficiency per flat (in tons per year and flat)

3. Conclusion

If in this given example the widow(er) can find an other smaller apartement and is prepared to move, it will increase the possible use of the former flat by 20%. (Tab. 2) Interesting is, that a move-management might bring more increase in resource-efficiency than the prolongation of the building-life-time by 50%. It is even as effectiv as a 50% energy-saving measure in space-heating through thermal insolation over the whole lifetime of the building or the energy-conscious selection of building materials (Tab. 3).

Further examples can prove the effects of vacancies in housing stock in terms of waste of resources. (Tab. 4)

As part of the housing policy the german government offert in the past six years a phantastic tax-incentive for investment in housing projects in eastern germany. As a result, yearly housing production increased by almost 50 % compared to 1988. At the same time the dramatic economic change in eastern germany did set off a migration from east to west germany. Today some municipalities and housing associations have vacancies in their housing stock of 15-20%. In the whole of east germany 500 000 dwellings are unoccupied, a tremendous waste of money and resources.[3]

If 10% of dwellings in a block of flats are unoccupied, or a flat is only over 90% of it's lifetime occupied, then energy-saving measures of 30% are outweighted by the effect of vacancies, because the loss of use is put on as a burden to the remaining flats. It means as well, that about 1,7 tons of building materials per flat and year are "consumed" without use. From this point of view one can say, that even an unoccupied flat emitts 1 ton of CO_2 per year in form of lost energy-input in materials and uncontrolled passiv heating. This takes even into account, that the flat is only passiv temperated by the neighbours. In the case of east germany this means a waste of 830 000 tons per year.

There will be great differences in significance of the issue for the different european countries, because of their different housing policies and loan-systems. But the calculation can show, that a good occupancy-management or a flexible housing market can in any case be an important contribution to higher resource-efficiency in the housing sector.

References

1. Deilmann, Clemens, Mai 1997, *Einfluß der Wohnnutzungen auf die Ressourceneffizienz*, in IÖR-Info Nr. 6, Dresden

2. Bundesforschungsanstalt fur Landeskunde und Raumordnung (Hrsg.), 1996 BfLR, *Nachhaltige Stadtentwicklung - Herausforderungen an einen ressourcenschonenden und umweltverträglichen Städtebau. Städtebaulicher Bericht,* Bonn

3. Eichler, Klaus, Prof. Dr.; Banse, Julliane; Effenberger, Karl-Heinz; Iwanow, Irene; Mobius, Martina; Roscher, Steffi; Fürll, Lothar; Schwarz, Michael, 1995, *Der Wohnungsmarkt der 90er Jahre in den neuen Ländern*, in IÖR-Schriften 10, Dresden

Environmental seal of quality for buildings - European experience

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Abstract
The dynamic character of the concept of sustainable development requires in the building sector a continuous improvement of the specific environmental performance. Ecological construction, that goes beyond general standards therefore needs voluntary engagement at the highest possible level. At the same time outstanding ecological "better-practice" in the construction industry can not sufficiently be distinguished from the growing number of exaggerating private eco-labeling. The (self-)declaration "Ecological", "Environmentally Friendly" or "Sustainable" building(-product) often appears widely arbitrary or highlights just single aspects of the overall environmetal impact of a building.

Therefore in the center of the here presented project stands the question, to what extend a neutrally embodied "Environmental Seal of Quality for Buildings" can contribute to solve this problem and which conceptual demands are to be set up for such an instrument.

For a best practical use and a contribution to further development and harmonization the approach will base on existing instruments. In a first step already practised attempts and existing experiences were documented, evaluated and compared. In the inquiry were included experiences from the FRG, Great Britain and the Netherlands. The analysis covered systems of indicators, methodological construction, methods of implementation, framing structural social, political, cultural and economic conditions, addressee and stratgies of marketing as well as the degree of independence, frankness and transparency of the methodology itself. Parallel to these empirical works fundamental conceptual aspects of eco-labelling were explored theoretically.

The paper sketches the essential theoretical basics and empirical cornerstones of an instrument, that serves as a guidance for the target groups (planner, clients, owner, user, financiers) and as a tool for strengthening the competitiveness of extraordinary voluntary environmental performance in the building-practice.

Diskussed are questions of institutional embodiment and conceptual elements like handling comprehensive sets of criteria for evaluation (e. g. "dual-track-approach": symbolic "signaling" with detailled information available in the background) or ways of marketing-effective and social respected awarding (e. g. certification and labeling under involvement of social groups of interest).
Keywords: Building, criteria, ecology, eco-labeling, environmental assessment, evaluation, marketing, sustainability

1 Introduction

The dynamic character of the concept of sustainable development requires in the building sector a continuous improvement of the specific environmental performance. Ecological construction, that goes beyond general standards therefore needs voluntary engagement at the highest possible level. At the same time outstanding ecological "better-practice" in the construction industry can not sufficiently be distinguished from the growing number of exaggerating private eco-labeling. The (self-)declaration "Ecological", "Environmentally Friendly" or "Sustainable" building(-product) often appears widely arbitrary or highlights just single aspects of the overall environmetal impact of a building.

In addition even the scientific basis of the ecological assessment of buildings is still uncertain. Because of the complexity of the structure of effects in the environment, possible side-effects and effect-chains are by no means finally recognizable. Still more difficult is a weighing of the different effects and side-effects.

In the everyday-practice genuine innovative building practice therefore can often not realize market-advantages when competing with simple "green-washing". With the growing common european market this problem furthermore tends to become a question of supranational regulation and equal opportunities in the European competition.

The support of exemplary ecological performance therefore requires a continuous further development of scientifically found and socially acceptable orientations for the estimation of the ecological effectiveness of the construction industry and their products as well as incentives to their transformation into everyday-practice. Therefore in the center of the here presented project stands the question, to what extend an "Environmental Seal of Quality for Buildings" can contribute to solve this problem and which conceptual demands are to be set up for such an instrument.

For a best practical use and a contribution to further development and harmonization the approach will base on existing instruments. In a first step already practised attempts and existing experiences were documented, evaluated and compared. In the inquiry were included experiences from the FRG, Great Britain and the Netherlands. The analysis covered systems of indicators, methodological construction, methods of implementation, framing structural social, political, cultural and economic conditions, addressee and stratgies of marketing as well as the degree of independence, frankness and transparency of the methodology itself. Parallel to these empirical works fundamental conceptual aspects of eco-labelling were explored theoretically. The results are brought together to a blue-print or framework for a comprehensive general "Environmental Seal of Quality for Buildings".

2 Why an eco-label?

It is a fundamental phenomenon, that observable features of a product in general have a stronger influence on market decisions than rather hidden characteristics. This potentially causes a continuing "adverse selection". In consequence buildings or building-concepts with extraordinary environmental (and health) characteristics can not use their higher quality to succeed on the market as they should do. This problem especially is expected to arise in the case of 'Innovators', which newly appear at the market with their products [Rubik et al.]. At the same time however 'Innovators' are required, since existing standards of environmental quality and performance in the construction industry are to be greeted of course as first steps, but do not suffice for a development of the building stock that is oriented towards the concept of sustainability.

Innovative developments can not or at least only on detours be supported by normative regulation (e.g. if actors are threatened with more restrictive legal standards to be expected in future). ‘Soft’ instruments like (financial) incentives, information and advice can be brought together in an environmentally oriented product-labelling. Environmental labelling therefore fundamentally offers the possibility, to support particular ecological performance on the building market. On one hand the supplier is given the possibility, to point out their particular ecological quality (“Signaling”). On the other hand the demand-side gets a first orientation about often invisible and rarely tangible qualities, which can so be included into the decision preparing information gathering process (“Screening”).

Different demands are to be fulfilled (criteria of ‘usefulness’) to let eco-labelling become effective.

First of all the target group of an eco-label must have a lack of information concerning the particular environmental qualities of a product. Such a deficit can be absolute (because of the innovativ character and the novelty of a product) or arise, if the required informations exist in principle, but however can not be processed by the individuals because of their multitude. Regardless of the reason of the actual deficit of information the requirement of information rises with the involvement which again rises with the longevity and the price of an asset. Trying to come to environmentally oriented decisions in the construction industry these aspects all become noticeable. Therefore it can be assumed, that from principle there should be a high demand for an environmental labeling of buildings.

To satisfy this requirements the mark or seal of quality must dispose of different characteristics. Generally we can say, that it mediates between the poles of “no information” and “information-flooding” by transforming the factual necessary information-input into an acceptable information-output. According to the concept of the label this transformation contains a more or less strong condensation of the information-input.

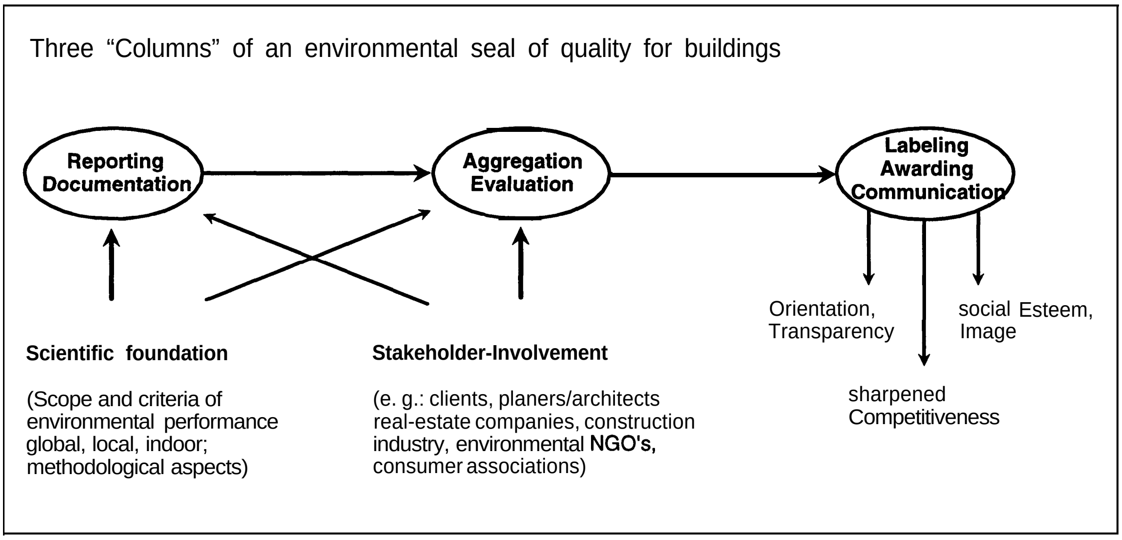

Fig. 1: The main elements of an environmental label for buildings (Blum, 1997)

On the input-side (Fig. 1: Column 1, “documentation”) first of all environmental labeling must record the material relevant environmental impacts as completely as possible. In the case of estimating environmental impacts of buildings this means for example to broaden the product-related scope with site-specific criteria. Especially regarding the concept of sustainable development it can furthermore be necessary, to include aspects of social usefulness and economic feasibility. In addition and since environmental impacts are by no means completely and finally recognizable even a seal of environmental quality with a comprehensive scope has to remain open for revision and adaptation of the used framework of criteria.

The completeness of the recorded information is an important condition of the acceptability of the instrument for the target group of the labeling. But indeed the criterion of completeness hereby is not only related to the actual fact of scientific knowledge but also to the specific requirements of the target group, to the relevance and usefullness of the information. The different possible levels of the aggregation or condensation of information within the process of product-labeling are corresponding with different demands on the recipients of the information. In the case of complex information that is not aggregated at all or aggregated only to a small extend a considerable effort is necessary for the interpretation and drawing of conclusions ("think yourself "). For various reasons (time, required background of knowledge etc.) in general this effort is hardly to handle in the every-day-practice. Highly condensed symbolic information (the typical symbolic eco-label) represents "pre-thought thinking". It requires to a wide extend the (blind) trust of the adressee of the information in the processed expertise. Labels of this type suit especially "for consumers with low involvement and for decissions concerning the purchase and use of products with low information requirements" [Rubik et al.]. Accordingly such symbolic labels alone will not be sufficient for the purpose of representing extraordinary environmental quality and performance of buildings. Rather instruments are needed in the practice of planning and building, that are able to give a quick orientation but at the same time keep accessible detailled information in the background if required. Thereby the instrument gains transparency and it is to some extent made possible to "follow the thoughts" while at the same time the necessary efforts for coping with the information are limited to a bearable extend. Moreover the transparency of steps of aggregation and evaluation (Fig. 1: Column 2) helps to strengthen the credibility of the labeling instrument.

Credibility is a further criterion of the acceptability of a seal of environmental quality. Beside the transparency of the instrument its credibility depends essentially on its institutional embodiment and probation and furthermore on the degree to what it is known to the public. It is directly obvious, that individual, company- or even product-related labels are recepted as less credible as such, which are organized through neutral institutions. This especially when the latter dispose of corresponding knowledge and reputation.

Looking from the point of view of the suppliers of extraordinary environmental performance ("applicants for labeling") an eco-label first of all should be acquired with acceptable expense and secondly emphasize the positive features of the offered product in a marketing-effective way. A seal of environmental quality fundamentally meets this requirements, since it does not enact a duty of declaration, but offers a voluntary instrument. By awarding only outstanding performance it helps to distinguish from other competitors. At the same time however thereby is said, that a labeling-approach is not suitable to separate out environmental unfriendly practices. The expense for the applicants for labeling is dependent on the applied concept of labeling. Here are some differences, which are presented in the following section.

3 How do existing approaches work

It is a common asset of already practised methods for the estimation (and awarding) of the environmental performance of buildings, that they do not wait for a last scientific clarification or evidence proving the one best way of ecologically correct building production. They rather emphazise, that despite uncertainty and scarce time-ressources nevertheless a consensus-based "better practice" has to get started and must be supported. Corresponding instruments build on a combination of scientific knowledge and political objectives of the institution that holds the label. The latter aspect once again refers to the significance of the institutional embodiment for the performance of an environmental seal of quality.

(Environmental) seals of quality for buildings are today already found with very different backgrounds. First of all three types of organisation can be distinguished by the degree of their public embodiment:

- Purely private eco-labels which are tailored to a special product of an individual company (e. g. a certain type of prefabricated building)
- Half-public eco-labels managed by superordinated (public) commercial associations as for example the so called "Quality-Communities" in the case of the german RAL-Quality-Certification and designed for a product line (e. g. wood-frame construction)
- Public or publicly authorized eco-labels (e. g. the german "Blue Angel", state-organized environmental competitions)

With each of these different approaches respectively different interests are joined:

Product-related private eco-labels try to reach an advantage on the market for the special product as directly as possible and with the slightest possible expense. "Seal of quality" may mean here, that terms like "Low-Energie-House" or "wood-frame construction" for instance are stiled to an inclusive symbol of environmental performance through corresponding advertising and often graphic emphasis although the underlying facts cover just single aspects at best. Of course there might as well be true environmental engagement to be found behind private eco-labeling, but the public acceptability however will allways be smaller, since the label will not be easily be able to prove its necessary objectivity.

Half-public eco-labels, for example in the administration of commerce-oriented public corporations, as well intend to further the competitiveness of the applicants for labeling. At the same time however the competition among the participants as well is stimulated through the independence of the label from individual firms and products. The primary objective is not to improve the chances of an individual supplier on the market, but the improvement of the transparency within a (qualitatively outstanding) segment of the market. Commercial but not company-related superordinated seals of environmental quality offer the applicant for the higher expense a higher credibility and with it a higher effectiveness.

Public eco-labels first of all aim at the advancement of initiative and innovation. Since especially innovative attempts frequently have to face disadvantages on the market (the phenomenon of "adverse selection") one can speak of an attempt of market-regulation if together with the outstanding environmental quality of a building or building-concept also a certain supplier is awarded. With the help of a seal of environmental quality the public intervenes in the competition of the market. An other case is given, if together with a (single) building at the same time the respective household or more generally the user (client or occupant) is awarded. So on the one hand we have the objective to support an outstanding and exemplary product and supplier and on the other hand the support of an exemplary (consumers) behaviour. Thereby this behaviour may also include the production of a building if this happens for the own use and not for the market ("user-client"). A distinction in this case primarily aims at social appreciation of an altogether exemplary conduct, but can however also be joined with the grant of individual advantages. Conceivable are here for example the award of state subsidies or also relief at the contact with the (building-)administration.

The different existing (authorized) approaches of (environmental) seals of quality for buildings now however do not only differ in the type of the institutional embodiment, but essentially also in their conceptual construction. The following fundamental elements can be derived in different combination from the up to now explored instruments:

- Certification based on a so called "building-passport" (formal frame of the documentation of technical and ecological data, partly under account of qualitative data).
- Completion of the "building-passport"-approach by adding extended technical documents and references for the use of the building ("operating instructions").
- Method of political appraisal. Offensively substantiating the selection of criteria according to political objectives on the basis of preparatory expert- and stakeholder-involvement
- Scoping and gathering of criteria under participation of stakeholders / "interested circles".
- Combination of building-ecology- and building-biology-related (concerning health of users) criteria.
- Linkage of the evaluation of technological and environmental quality.
- Modular construction of the programme of evaluation. The catalogue of criteria is subdivided in obligatory and additional voluntary elements. The certificate then refers to the chosen scope of evaluation.
- One-dimensional approach (e. g. use of energy) but very dedicated objectives in detail (e. g. high rates of reduction of the output of CO_2) as pragmatic attempt.
- Deviations from standing norms and rules (e. g. in the case of innovative building technology or materials) are documented and regulated in private contracts.
- Methods of relative evaluation. The scale is not defined by (individually) alleged objectives or limits. Measured is the extent to wich existing average environmental performance is met or exeeded .
- Temporal limitation of the validity of the certificate/award.
- "Cheque-book"-method for the organization of contacts with executing companies ("cheques of quality": quality demands, documentation of execution) as well as with a (contracted) office for advice and certification ("cheque of certification"). This method was introduced referring to a repeatable building-concept.
- Inclusion of the period of the use of the building into the evalution. Linkage of the assessment of the environmental quality of the product (building) and the ecological responsibility of the consumer (owner/occupant of a building). Special emphasis hereby is given to the aspect of social appreciation of good examples.
- Opportunity of developing the evaluation-method into a component within a tool for building-/facilitymanagement.
- "Positiv List" of ecological friendly building materials as an element of the criteria of

evaluation as well as of good advice.

- Certificates of evaluation in some cases completed by symbolic elements (e. g. "Green Street Number").
- Combination of the evaluation/certification with a competition, that promises further public awarding of the most outstanding examples ("the Best of Best").

4 Drafting the basics of a general environmental seal of quality for buildings

The first overview over existing approaches of evaluating and awarding environmental performance within the building sector elucidates their heterogeneity. The main differences are found looking at the systems of criteria/indicators and the above sketched conceptual particularities. The span of the possible sets of criteria ranges from single-media-oriented approaches (soil-sealing, use of energie) over media-integrated "ecological" (land-use, water, air, resources . ..) up to sustainability-oriented attempts (trying to integrate ecological, economical and social questions).

In order to distinguish and award outstanding voluntary performance in the building sector the scope of a comprehensive environmental seal of quality should be as wide as possible. Even aspects of social usefulness and economic feasibility may be taken into account when the longevity of buildings, their impact on the environment and the concept of sustainability are to be considered. Furthermore because of the interaction of the building with its (direct) environment/surrounding the used framework of criteria has to be open for the inclusion of site-specific criteria.

For the practical use of an environmental seal of quality it should be helpful, to evaluate environmental features together with more general aspects of building-quality. Hereby interrelations are given to the discussion on "Total-Quality-Management" in the construction industry (linking of environmental-, quality- and safety-management).

At the same time however a comprehensive scope leads to the problem of handling the instrument. With the extent and the complexity of the system of indicators increases the effort of recording and documentation for the applicants for labeling as well as the effort of interpretation and conclusion for the target group. Of course the effort of interpretation can be reduced by aggregating and condensing the numerous indicators to a symbol, but at the same time however the instrument will lose transparency and thereby credibility. This counts especially for such complex products like buildings. Conceptual approaches have to be found, which face this dilemma. But by no means too pragmatic attempts, such as structuring the instrument along the disposable data-sources, should be pursued.

A possible approach is for example, to use a comprehensive system of indicators within a modular concept, that differentiates the aspects to be considered according to the particular case and circumstances. Unquestionable such an approach (of "conscious chosen incompleteness") should be prefered in comparison with short-sighted pragmatic attempts. It also offers great advantages concerning the credibility of the evaluation(-instrument). In the first case the aspects, that were not considered, remain as a future duty, while in the second case the gaps of the consideration come to the fore either not at all or at best by chance. Another possibility of handling a complex information input is a "dual-track-approach". Hereby selected criteria can be aggregated and condensed to a symbolic eco-label while a the same time in the background comprehensive information is kept available. Such a construction especially is recommended in the case of complex products like buildings with high "consumer''-involvement, where consumers are expected to ask for detailed information. A “dual-track-approach” offers the addressee of a seal of quality a symbolic pre-interpretation (like the british “Green-Home standard award”) and at the same time reduces the dependence on experts by allowing own conclusions on the basis of comprehensive background-information (e. g. so-called “building-pass-ports”).

The decision for (selected) criteria that have to be refered to within an evaluation method is allways a political decision. It may be be prepared but not replaced by scientific work. Therefore the used scope and systems of criteria must be open for regular revision and/or adaptation. It is important for the meaning and effectiveness of the instrument who is entrusted with this process of criteria-gathering and -revisiting. Fundamentally one can distinguish the work of an internal or external commission of experts from a jury-process under participation of social groups of interest / stakeholders.

Public instruments certainly should prefer a jury-process. A well known example is the german “Blue Angel”, which though is occasionally critizised for its too little dynamic. Beside the regular revision and adaptation of the scope and criteria the dynamic character of an environmental seal of quality for buildings schould furthermore be ensured by a suitable form of temporal limitation of its period of validity. Only by this way the currently most outstanding environmental performance of building-practice can be distinguished and awarded without devaluating earlier examples.

Regarding the above sketched essential cornerstones we can go further to develop an instrument, that serves as a guidance for the target groups (planner, clients, owner, user, financiers) and as a tool for strengthening the competitiveness of extraordinary voluntary environmental performance in the building-practice.

References (e. g.)

- Adriaans, R. (1996) Qualitätssicherung im Hochbau und die Entstehung des AKÖH; in: Arbeitsseminar Produktprüfung der ECOHB am 26.10.96 im Öko-Zentrum NRW, European Cooperation of Organizations for Environmetally-conscious and Healthy Building (ECOHB), Bosco Büeler, Flawil (CH)
- Blum, A., Deilmann, C., Neubauer, F.-S. (1997) Grundlagen eines Umweltgütesiegel fur Gebäude. Dokumentation, Auswertung und Vergleich autorisierter Bewertungsmethoden fur Gebaude-Umweltrelevanz, IÖR-Forschungsbericht, Dresden
- Rubik, F., Weskamp, C. (1996) Verbraucherschutz durch Produktkennzeichnung, Schriftenreihe des IÖW 98/96, Berlin (D)
- Ministerium fur Umwelt, Energie und Verkehr (Hrsg.; 1996): “Die Grüne Hausnummer”, Information aus der - Serie 1 - Bauen und Umwelt - des Saarlandischen Umweltministeriums, Saarbrücken (D)
- Prior, J. J., Bartlett, P. B. (1995) Environmental Standard - Homes for a greener world, Building Research Establishment Report, Garston, Watford (GB)
- Haas, M. (1997) Milieu Classificatiemodel bouw - TWIN Model, Proefschrift, Bussum (NL)

Project Management - the agent of sustainable production?

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Abstract
The construction process follows an identifiable life cycle, beginning with the initial conceptualisation by the project sponsor, through to the commissioning and operation of the completed facility, and ending with ultimate demolition and disposal or refurbishment and remodelling for an alternative use. Project management is that discipline which is engaged for the greater part of that lifecycle and occupies a unique position to exercise influence over the conduct of the process and the characteristics of the product. This function provides project management with the opportunity to be significant in the determination of design criteria, methods of production, resource allocation, and operational standards, and the identification and analysis of risk. As such it may be argued that the discipline of project management may be the primary agent for the realisation of significant change in the manner of construction to achieve objectives of sustainability whilst meeting the performance requirements of the project sponsor.

This paper examines the influence of the project management role as follows:

- the means by which consonance may be achieved between the expectations of project sponsors and the capability to conduct the project in a sustainable manner
- how the comprehensive relationship between the project manager and the project over its lifecycle may be exploited to achieve significant change in the planning, resourcing, and execution of the production process
- how conflicts and ethical dilemmas which occur in the project process may be satisfactorily resolved, and how project risks may be identified and interpreted and their impacts influenced, whilst maintaining the pursuit of sustainable construction

This discursive paper has been based upon a review of contemporary literature in the fields of project management, sustainability, and risk management, and applied to the context of construction practice. The argument is proposed that the pivotal position of the project manager in the project process, and the vital relationship which occurs with the project sponsor, result in the project manager becoming the most likely agent for the realisation of sustainable construction practices. The paper concludes with the identification of the profile of a sustainable construction project which is more likely to be realised as a consequence of the influence of project management.
Keywords: construction, project management, project manager, risk, sustainability.

1 Introduction

The construction of buildings invariably results in the extensive, often profligate, consumption of resources and materials, and substantial, often irreversible impacts upon landscape, amenity, and ecosystems, whilst meeting social and economic needs for shelter, investment, and the satisfaction of corporate operational objectives. The process of construction can be seen to pass through a recognisable life cycle from the original conceptualisation of the project by the project sponsor, through construction and commissioning, to eventual occupation and operation up to the point of evacuation, demolition, or renewal and refurbishment. This cycle is largely the subject of project management which seeks to achieve the realisation of the built entity, primarily in a manner consistent with the needs of the project sponsor, but increasingly in a way which meets the expectations of an increasingly diverse and influential body of project stakeholders [1]. These stakeholders will hold a range of expectations of the project and employ a diversity of performance criteria against which the success of the project will be measured. Increasingly the ability of a construction project to meet objectives of sustainability in its design, formation, and operation are coming to the fore.

An essential element of the project management role is the resolution of conflicts and ethical dilemmas which arise when stakeholder objectives are not in concordance with each other or all capable of mutual satisfaction. In particular the project manager is responsible for advising upon or executing critical project decisions, including specifically the opportunity to promote a sustainable approach to construction activities, which would be undertaken within the context of explicit project sponsor requirements which will vary in their degree of support to a sustainable approach. The issue to be debated in this paper is to what degree the project management discipline may be the active champion and implementer of a sustainable approach.

2 The role of project management

There is a growing awareness that industrial and business practices will have the most significant impact upon the future well-being of natural systems. It has been that noted (2) that *"sustainable development....... recognises that economic growth and environmental protection are inextricably linked, and that the quality of present and future life rests on meeting basic human needs without destroying the environment on which all life depends"*. This view identifies a critical responsibility that is placed upon those responsible for structured productive activities to execute these in such a way that there is a commonality of interests and expectations amongst both industrial and environmental sectors.

The extension of the above argument is that the role of project management for construction is the planning, acquisition, and application in a controlled manner of all the resources, both material and intellectual, needed to bring about the organisational objective of creating a built entity, in such a manner that does not consume resources in a wasteful manner, has at worst a neutral visual impact, and does not become the source of unacceptable emissions.

The role of project management in construction is to act for the project sponsor in such a manner as to seek to optimise performance criteria in respect of the technical performance, investment realisation, and operational satisfaction of the completed facility. This pursuit of optimisation inevitably results in the sub-optimisation of certain outcomes which may include environmental impact. However the success criteria for evaluating project performance is increasingly extending beyond compliance with technical standards to embrace some degree of social responsibility and demonstration of ethical behaviour. Sustainable construction practices are capable of being delivered in a project context where a condition of mutual benefit can be created. Where a sustainable approach can be recognised as coincident with sound business practice then a natural stimulus for this occur will be present but the mobilisation of ethical behaviour can receive further impetus from such drivers as state legislation, market incentives, and stakeholder pressures (3).

Each of these spheres of activity present the medium in which the pursuit of sustainable construction may occur and demonstrate the potency of the project management discipline to exercise influence over the environmental impact of the construction process at a number of levels and on a range of occasions as it exploits its significant position to determine critical principles of execution. This role may, however, present ethical, professional, and managerial issues arising from the project manager/stakeholder relationship where there is little coincidence between the commercial, technical, and functional requirements of the project and the promotion of sustainable means of delivery and the diminution of environmental impact.

3 The case for sustainable construction

Any rational case for the promotion of sustainable construction practices must initially be founded upon an ethical justification, that is *"the attempt to apply moral theory to the human treatment of natural objects"* (4). This basis is further reinforced by the views of the environmental pessimists that changes in patterns of consumption, recycling, and conservation of resources are vital for the long term viability of mankind (5). However this gloomy prognosis is neither universally recognised or accepted, resulting in sub-optimisation of resource utilisation and environmentally efficient practices. The ultimate stimulus towards the wider acceptance of environmentally sensitive practices is only likely to occur when such approaches become coincident with good business practice. The position that *"good business is good ethics"* (6) seems to be powerful and engaging even though the reverse of that position is frequently not found to be true.

A critical role of the project manager who is charged with the responsibility for achieving the realisation of a built entity is to resolve the conflicts and ethical dilemmas which emerge and to make critical strategic and executive decisions, many of which will have a profound impact upon the sustainability profile of the process. For the construction process to achieve a significant orientation towards sustainable practices an adaptation of Thorsby's principles ('7) is of value:

- *advancement of material and non-material well-being* - the development of buildings not only as stores of value and generators of economic activity but also as promoters of enhanced standards of health, education, amenity, and security

- *inter-generational equity* - modifying the land and executing buildings in such a way, and employing such technologies, as to leave no hazardous or wasteful legacy for future generations
- *intra-generational equity* - conducting the process of development and construction in such a manner as to be an instrument of equnable trading practices and resource distribution
- *protection and maintenance of ecological processes and systems* - the design, management and execution of a constructed facility in such a way as to protect, value, and cherish, even enhance, local environments
- *dealing cautiously with risk and uncertainty* - adopting a cautious and well-informed approach to risk identification, assessment, and exposure, which arise from construction activity, particularly where an environmental risk impact would be harmful
- *recognition of global dimensions* - adopting practices for resource acquisition, energy consumption, and emissions control which are not harmful or damaging either locally or beyond national boundaries

The above implies the prevailing view that there is an inherent conflict between commercial and environmental interests in which the commercial or organisational benefits arising from a project accrue to the project sponsor whilst environmental costs are defrayed over a widespread population and ecological system The project manager holds a pivotal and influential position in the project delivery process and thereby acquires the opportunity and means to establish a balance between commercial and environmental interests and to be innovative in promoting sustainable practices as an important component of the commercial process of construction.

4 The project management of sustainable construction

The project management function is that which is consistently present throughout the life cycle of the construction project process and as such holds a unique position of influence over the manner in which a project shall be conducted. The project manager is central to the decision and information passing network of the project and has a direct relationship with the project sponsor. The project manager executes his responsibilities by means of the powers vested in him which are derived from a combination of the formal powers transferred to him from the sponsor and the influence he is able to exercise over other participants in the project process. The extent of this influence is determined by the personal effectiveness of the project manager and the degree to which the ambitions and objectives expressed by him are accepted and endorsed by others. The project manager's function is to search for points of agreement, to examine the situation critically, and to think reflectively, and only then to take a decision based on the perceived superiority of his knowledge (8).

The implementation of the principles of sustainable construction can only be achieved where there is an active acceptance of the concept by all participants in the project process, primarily the project sponsor and key members of the design and production team, operating under the motivational and directional influence of the project manager.

Historically the realisation of a constructed entity has been interpreted as an application of technological actions and processes which present an array of technical solutions from which a considered selection can be made. The adoption of a sustainable approach has the effect of eliminating some options, generating new alternatives, and modifying others. The application of technology is not always benign and exponential technological growth can not always be relied upon to create an ever-expanding resource base ahead of demand. Effective leadership emanating from the project manager who enjoys the support of an enlightened project sponsor and is empowered with the appropriate level of delegated authority to direct the design, procurement, and construction process, is the manner in which appropriate technologies may be harnessed in the pursuit of sustainable construction.

The direct relationship which exists between project manager and sponsor offers the opportunity for critical policy decisions to be made during the project life cycle which can form the pathway for project delivery based upon sustainable methods and minimal environmental impact. The key contributions made by the project manager can include:

- The provision of leadership and direction to the project process to establish a project team culture consistent with the intention to conduct a project in a sustainable manner
- The articulation of clear goals and project outcomes in terms of sustainable construction processes
- The identification, appointment, and assembly of a construction project team of like-minded collaborators to further the realisation of the sustainable objectives
- The influencing of the project sponsor towards the opportunities and benefits of a sustainable approach and how this may promote enhanced value and user satisfaction
- The establishment of the guiding principles by which a project may be delivered in a manner consistent with sustainability and ethical responsibility
- The planning of a procurement and resource acquisition route based on equitable commercial relationships and the pursuit of efficient resource conversion

These contributions are consistent with the 'precautionary principle' that demands th.at preventative action should be taken to avoid environmental damage as far upstream in the project delivery process as possible, a function which falls directly to the project manager who has the empowered opportunity to determine the design and manner of construction of a built entity.

5 The management of the risk of project non-compliance with sustainability

General risk has been defined (9) as *"exposure to the possibility of economic or financial loss or gain, physical damage or injury, or delay, as a consequence of the uncertainty associated with pursuing a particular course of action." An* extension of this definition may be that which encompasses the prospect of a construction project falling short of standards of sustainability which are being sought. The risk impact of such a shortfall would be distributed over a wide range of recipients, the majority of whom did not voluntarily place themselves at such risk. Risk management, or the process of dealing with risk, implies some form of measurement of uncertainty based upon informed predictions of outcomes.

For a construction project the environmental impact of certain processes or activities may be predicted with confidence and certainty, others may be chance outcomes dependent upon a host of operational variables. The greatest uncertainties occur during the early conceptual phases of a project when decisions of the greatest impact upon project outcomes are concluded (10). Risk management of sustainability may be viewed as a three stage process:

- Risk identification - the recognition and assessment of the environmental risk impacts which are expected to occur as a direct consequence of intended construction activity. Once a risk has been identified it becomes a quantifiable managerial problem
- Risk analysis - the disciplined gathering of data to permit the systematic and reliable interpretation of the probabilities of environmental risk impacts occurring and the scale of their impact. It is likely that a range of occurrences will be identified which are likely to present a spectrum of potential risk impacts upon the environment as a direct consequence of construction project activity.
- Risk response -the development of an appropriate response to the identified and analysed risks to the environment in order to seek to mitigate or eliminate the adverse effects by the promotion of sustainable practices

The response to the potential for environmental risk occurrence can take a number of forms dependent upon diverse factors derived from the orientation of the project sponsor and the project team towards the objectives of sustainable construction, the dynamics of the economic, legal, and social context in which the project is to take place, and the scope for risk impact mitigation, transfer, or avoidance. These factors can be generalised as:

- awareness of the impact of risk events beyond immediate project boundaries
- capability to recognise both generic risks and project specific risks
- level of expertise in risk evaluation techniques
- ability to evaluate unique risks or benefits arising from novel procurement, resourcing, or execution arrangements

For commercial organisations the impact of the incidence of almost every risk event can be measured in financial terms as the effect upon turnover, market share, and profitability, even if the initial risk impact falls upon an operational feature such as product or service quality, reputation, or technological advantage. In the context of sustainable construction activity a risk impact will occur at a number of levels:

- specifically within the boundaries of the site or existing building e.g. material conversion inefficiencies, hazardous processes, energy intensive product
- locally in the immediate environs of the location of construction activity e.g. vehicle movements, building emissions, aesthetic impact
- remotely where the demands of the construction process influence methods of resource provision e.g. material extraction, transport movements,

The authoritative and influential role of the project manager allows for the establishment and implementation of measures to identify and analyse the prospects for risk occurrences which may arise and which would conflict with the expressed aims of sustainable construction. It is the project manager who holds the organisational role and capability to implement procedures to ensure that methods of construction, the means of resource acquisition, and the impact of the process and product of construction, are sustainable at every level of impact and that any harmful legacy of construction activity is diminished or eliminated. The project manager is equipped to fulfil this role due to the managerial and technical sills possessed, the ability to impose methods of operation upon participants and collaborators in the construction process, and the capacity to direct and select modes of delivery due to the delegated authority derived from the project sponsor. By these means risks to achieving objectives of sustainable construction will most certainly be more assiduously identified and analysed and their impacts avoided, mitigated, or transferred, with the result that the construction practices carried out and the characteristics of the product of this activity may be consistent with declared sustainable criteria.

6 Conclusion

The critical position of the project manager in the construction process means that the holder of this role is uniquely qualified to be the primary determinant of the mode of execution of construction activity. Sustainable construction is most likely to occur where there is a synergy arising between the aspirations, value systems, and sense of social responsibility of both project sponsor and project manager who have the most intimate relationship within the project process. Under the project managers expert stewardship the performance standards may be formed in such a way as to permit the optimisation of all elements by a careful process of matching and balancing. The project manager who is acting in an agent role in respect of the project sponsor is the most likely project participant to achieve a profile of sustainable construction to include:

- a balanced mix of performance criteria including technical conformance, economic viability, aesthetics, environmental harmony, and user well-being

- an extensive range of solutions to design, construction, and performance issues derived from innovation and creativity
- a broad vision of risks to successful sustainable construction delivery and the consequences of project decisions

The project manager should be able to promote a sharing of objectives and values amongst project participants which are consistent with organisational requirements and economic performance criteria. This is most likely to be achieved when appropriate managerial skills are applied and allied with technical competence and a breadth of vision of the impact and legacy of sustainable construction activity. As noted by the CEO of a major industrial organisation a common ground between sustainable practices and commercial goal achievement is identifiable (11): *"Far from being a soft issue grounded in emotion or ethics, sustainable development involves cold, rational, business logic".* Project management is the organisational discipline which is capable of bringing about this commonality of interest.

7 References

1. Oldfield, A. and Ocock, M. (1994) Project Risk Management: The Importance of Stakeholders, in *Proceedings of 12th INTERNET World Congress on Project Management,* Oslo, Vol. pp.
2. Schmidheiny, S. and the Business Council for Sustainable Development [BCSD] (1992) *Changing Course: A Global Business Perspective on Development and the Environment,* BCSD and MIT Press, Cambridge, USA.
3. Hutchinson, A. and Hutchinson, F. (1996) *Environmental Business Management: Sustainable Development in the New Millennium,* McGraw Hill (International), UK
4. Sorrell, T. and Hendry, J. (1994) *Business Ethics,* Butterworth Heinemann, London.
5. Papanek, V. (1995) *The Green Imperative,* Thames and Hudson, London.
6. Friedman, M. (1984) The Social Responsibility of Business is to increase its Profits, *in Business Ethics* (1990), Hoffman, W. and Moore, J. (Eds.), McGraw Hill, New York.
7. Thorsby, D. (1993) Ecologically Sustainable Development and the Transport Sector, in *UNEP Industry and Environment,* 16 (1-2), pp 15-17.
8. Harrison, F.L. (1985) *Advanced Project Management,* 2nd. Edition, Gower, London.
9. Ward, S.C. and Chapman, C. (1987) *Risk Analysis for Large Projects - Models, Methods, and Cases,*
10. Amos, J. and Dent, P. (1997) Risk analysis and Management for Major Construction Projects, *in Proceedings of RICS Construction and Building Research Conference,* Portsmouth, United Kingdom.
11. Magretta, J. (1997) Growth through Global Sustainability, *Harvard Business Review,* January-February, pp 79-88.

Analysis of the primary process for efficient use of building components

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Abstract
Sustainable construction as such is not additional factor in building decision making, but an essential part of the prices which should reflect scarcity of the resources. It should not only be focused on avoiding pollution and use of exhaustible recourses in (new) construction and demolition. Important is minimised environmental effects as an annual average over the life span of the technical solution. This needs annual cost calculation and proper (functional) demand period definition. Technical life span has to be reduced or lengthened by using the flexibility principles of open building. Analysis of the primary process in terms of performances and demand period should be the starting point of decision making.
Keywords: sustainable construction, open building, performance concept, service life, functional demand period.

Introduction
A building is a technical solution to fulfil1 demand for services to be used in a primary using process. The solution has to be considered as a stock of services which usually can be supplied over a period much longer than demanded for. This causes inefficient use of resources; which especially becomes clear when transformed to an annual basis depending on the economic life span.
It has to be tried to minimise negative consequences by using a good basis for decision making and demand definition as well. A systematic description of the demanding process is essential.

1. Sustainable construction
For a long period construction was focused on the maximisation of the life span of a building; like in the Roman era [9]. In this century, especially after the Second World War, construction most of the time had to be cheap and as a consequence buildings lasted rather short for the purpose initially meant. Both types of construction goal mostly are in conflict with sustainable construction.
Sustainable construction is a new problem area, since the responsibility for the existing stock of buildings is now becoming to be actual.

In fact this problem depends largely upon on the stage of development of a country. As showed by Bon [5] and Batten [2], the share of construction activities in the national production of a country can be described by a 'bell-shaped' curve. On the right hand side of the bell it is the quantity as well as the quality of the construction activities which is changing (see figure 1). As soon as enlarging the stock will be substituted by maintenance and replacement we become aware of the consequences of service lives shorter than initially expected and/or solutions which cause high disposal costs.
This effect is even stronger in countries which have enlarged their stock of buildings at high speed after the Second World War. Focus was on fast and cheap construction (sometimes initiated by the government), without taking long run cost and environmental consequences into account [2].
Sustainable construction has to concern the period from 'cradle to grave' [28], and as a consequence the 'sustainability scale' has to include time: i.e. the service life.

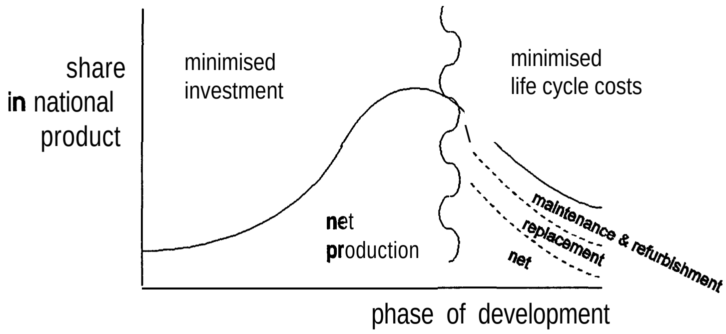

Fig. 1 A quantitative and qualitative change in building production

2. Focus on service life

Environmental consequences of the need for a built environment have to be minimised in the long run. So it makes no sense just to minimise the negative effects at the moment of new construction and of (partly or final) demolition, because they have to be related to each other and to future construction and demolition activities which are meant to generate new supply according to continuously changing demand.
The period over which a building or a component will be used is very important information when an investment decision has to be made. It is really a shame, that it is not an exception that a building is demolished before half of the potential service life [28]. An important goal should be to extend the life of non-renewable resources by reuse and recycling and as a result to minimise the environmental effects of having buildings available [8]. As a consequence, it is the life cycle operation which should be our concern [12], which should include the environmental effects of demolition in order to be able to consider a long but realistic planning period. However, we have to face the contradiction that on the one hand the expected life span is overestimated [17], while on the other hand the period of (financial) interest of the investor/decision maker in the building usually is very short since they consider a building as a

speculative investment [19].
Minimisation of environmental consequences in the long run means that the consequences have to be transformed on an annual basis; a realistic planning period taken into account. In some way the sacrifices, to have a built environment available, have to be measured in financial terms, so consequently we may focus on -properly calculated- minimised annual costs [18].

3. Prices reflect scarcity

It is a problem of environmental economics to transform the various consequences of our production and consumption processes into prices. The compensation for pollution and the use of exhaustible resources to guarantee an acceptable environment in the future should be incorporated in the price of the built environment. As a consequence sustainability should not be added to performance, quality and costs [12], but is an essential ingredient of the costs. We need full-cost at real-cost-prices as meant by Hill and Bowen, as has been defined within their economic principles [9]. Only when prices are determined in such a way, they can be used as an allocating parameter in decision making like the choice out of technical solutions to fulfil1 our demand for adequate shelter over a well-defined period. It is essential that disposal costs are -as a consequence of one of the construction activities- included in the annual costs of a component or of a building, since they have to be paid by the user of that component or of that building [25].

4. Activities and costs

The activities which have environmental consequences have to be transformed into annual costs in order to be able to choose the best solution in the long run [24]. All activities, which result in an usable built environment have to be taken into account, as well as the activities which bring us back to the initial situation. The letter activities are essential in sustainable building, of course.
The annual costs to be calculated should concern (only) the components which are present at the moment of calculation. We have to take into account all disposal costs of these components, since we want to create in he future a situation of free choice for components to be installed at a moment of adjustment; like upgrading or refurbishment. To the construction and disposal costs have to be added the expected maintenance costs over the expected service life.
By means of annuity calculation these costs will for each component or group of components be transformed into annual costs over the expected service life. The structure of the cost picture of a building is illustrated in figure 2. Each moment of choice for construction activities is a moment at which we start from ‘relative’ scratch. The expected service life is a parameter in decision making, which influences the level of annual costs.

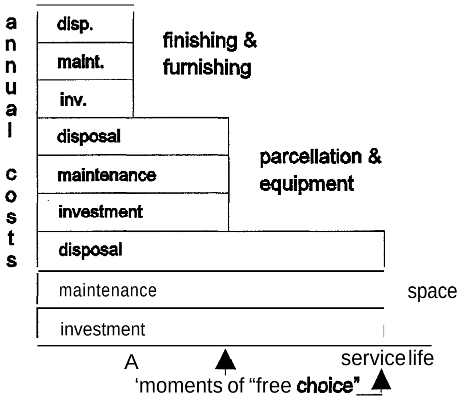

Fig. 2 Cost structure of a building; split up in three service lives

5. Economic life span as optimum

The optimal life span concerns the period over which the annual costs are minimised and in which the solution will really be used as meant initially. From the technical point of view several solutions are able to supply the services over a much longer period than demanded for, and in fact such solutions usually are chosen and produced. However, solutions have to be chosen which can live not much longer than the expected useful life [11]. To put it differently: the life should be determined by the earning power of the using process [16] or the stock of services should not exceed the desired life span [28]. As stated by Rutter [15] and Wyatt [28] the designed life has to be matched with the economic life.

Three 'periods' have to be defined in order to be able to find the optimum [23].

We have to be sure, that demand is defined without regarding to technical solutions in order to be able to choose the best solution from the cost and quality points of view. The demand period concerns the period over which a function is needed and does have to be the same as the life span of the solution; we will use he term functional demand period, which is not connected to an object. To each technical solution a technical life span is connected. The choice concerns the economical life span, which can be equal to the technical life span, but usually equals the functional demand period, but can be shorter as well.

The various periods defined are illustrated in figure 3.

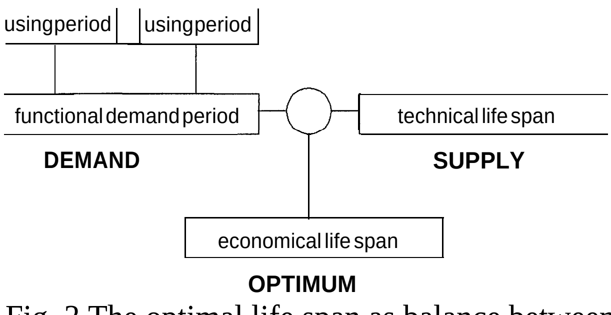

Fig. 3 The optimal life span as balance between demand (fdp) and supply (tls)

6. Balancing costs over life span

The annual costs can be minimised by influencing the costs of construction activities, but the result depends heavily on the related life span. From the demand side a more simple solution than usually chosen would be acceptable, and probably cheaper on an annual basis. In many cases the functional demand period is decisive and equal to the period over which the optimal solution will be used: the economic life span.

It may happen as well, that the technical life span is shorter than the functional demand period, in which case the solution will be replaced identically one or more times within the functional demand period.

Some times -this is important for sustainable construction- a technical solution may be used in different positions by several users. In this way the economic life span as well as the underlying functional demand period incorporates several using periods (fig. 2). In that case we have to add the cost of transfer of the (group of) components to the initial construction costs, the final disposal costs and maintenance cost over the range of using periods.

When the functional demand period for the services of a group of components is very long, it may be realistic to spend more on construction and disposal, since the costs will be spread over a long period. Another option is to fulfil1 demand by identical replacement of a technical solution, which is realistic when the costs of activities will diminish more than proportional, compared to the shortened life span.

When we have to do with short functional demand periods there is no reason to try to build for the very long run. This only can become clear when we really transform costs of activities to annual costs on the basis of realistic demand periods; not the basis of the technical life span which can be met.

The best solution can only be found when demand has been defined properly; the functional demand period included.

7. Complex demand definition

The functions we need for our production or consumption processes are very complex of character; they concern a group of functions which can be chosen rather freely from he technical point of view. Although we can only choose those combinations which fit within our budget [14], there still is a lot to choose. Since we have argued that the period over which functions will be demanded for (functional demand period) is important for decision making based on annual costs that time has been added to demand definition.

We agree with Masters [13], that service life prediction is not easy. To make it even more complicated, we have to deal with a range of planning periods (fig. 3). Demand for floor space can be defined for a longer period than the demand for e.g. climate or the parcellation of space. As a consequence the technical solutions serving different demand periods have to be made technically independent as well.

A dynamic program of functions -a scenario- has to be defined to make an efficiently flexible or adaptable environment possible.

For each function or type of performance a functional demand period has to be defined.

8. Building as set of technical solutions

As a consequence of a wide range of functional demand periods we can expects a range of technical solutions and economic life spans as well. Since some solutions will be used over a longer period than others, the building will be adapted constantly [6]. Buildings can only be used properly in the long run when a deconstruction and disassembling analysis has been made [29] and a replacement without impair of functions of others can be accomplished [10].
At the moment of new construction we have to take into account that some components will be removed after a short period and it may be advantageous to install them in later stages of the construction process (fig.4) and to make decomposition easily possible by introducing connecting components [7]. Open Building is still actual, if focused on future adaptations.
A building is a complex durable means of production, while for each part of the complex costs have to be calculated more or less separately.

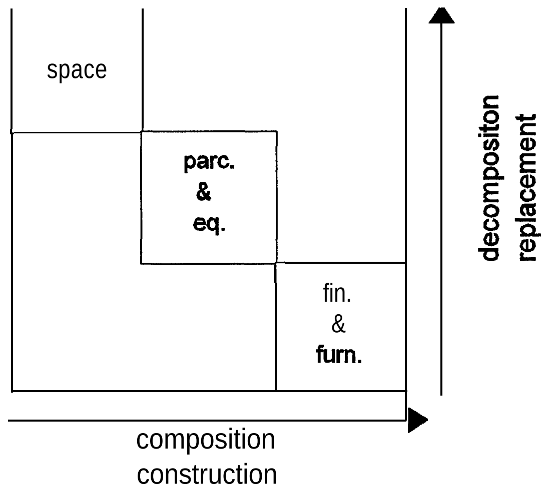

Fig. 4 Construction in view of future replacement

9. A demand and replacement scenario?

Information about future demand is necessary to create a sustainable built environment. However, we have to decide whether we have to formulate demand over the expected life of the building or over a shorter period. It has to be decided to which extent future demand has to be predicted in a scenario.
Since we know, that changed demand (at least a change which results in misfit which needs an adaptation) will result in rehabilitation activities, the decomposition of the building can more less be predicted.
However, we do not have to know which replacing components will be installed in the future. It is enough to know which components will be removed and after which period. As than can be decided about the materials to be used and additional investments to make easy removal possible; the connecting components. Concerning

the building as a set of technical solutions, a decomposition scenario is needed; a replacement scenario is not essential (fig. 5).

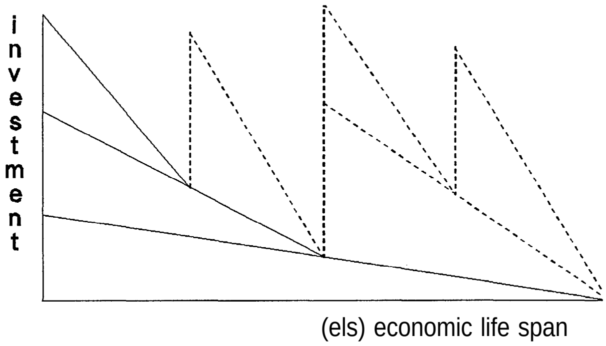

Fig. 5 Building as changing set of technical solutions (Tempelmans Plat, 1985)
-----------------------------------decomposition scenario
________________replacement scenario

Consequently a demand scenario over a long period is not needed; information of the functional demand periods at the moment of new construction or of adaptation is enough (fig.6).

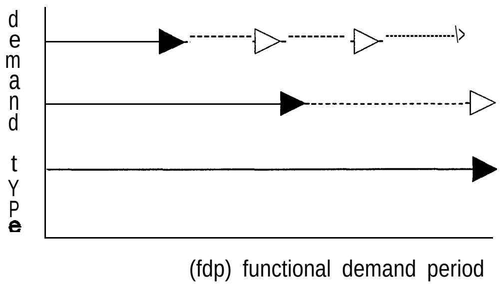

Fig. 6 A “constant” demand scenario at the moment of new construction

10. Symmetry of supply and demand
After the balancing procedure of supply and demand, we find a solution in which the set of functional demand periods is mirrored by a set of economic life spans of the solutions (fig.7). For each combination of demand and supply the annual costs are minimised.
Such a result can only be obtained when for each function the demand period has been defined. However, since we want -because of reasons of economy- to combine future adaptation activities the range of periods has to be limited, see figure 6.

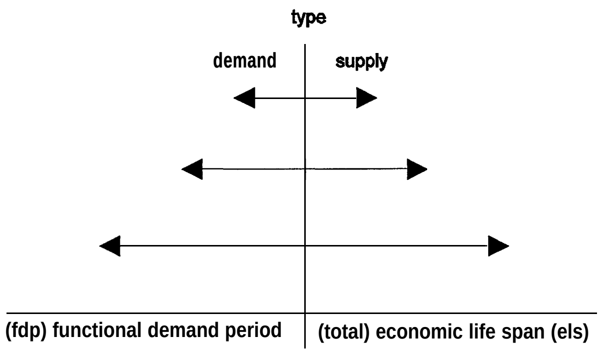

Fig. 7 Symmetry of demand and supply to minimise waste

11. Analysis of the primary process: performance concept

To make the choice out of technical solutions as free as possible, demand should not be defined in terms of solutions. This is the basic idea of the performance concept, which however -according to Becker [3]- is hardly used in practice in the proper way. The first problem concerns the demand definition from the point of view of the user. He should be able to define the functions which are needed for the activities as part of the using process; demand defined in business language. These functions have to be translated into performances to be supplied by the technical solutions; defined in building language [1] We can not expect from the user that he is able to transform his demand in the best technical solution. It would even not be wise, since the user is an amateur in that field.

The second problem is to define performances which can be measured and to which costs can be allocated. When climate is needed as a function, we can measure it in e.g. degrees temperature and percentage of relative humidity. Costs can only be added when the space and period over which he climate is needed is know to the decision maker. Figure (8) illustrates the transformation from function to solution and the reverse concerning cost allocation.

The third problem concerns the complex relations between performances and solutions. Climate can be measured in e.g. two types of performances, but for these performances several components may e needed. We need in his example outside walls, a roof and a heating system. Above that complication we have to face the fact, that a component may be needed for the supply of more types of performances, like components connected to sound insulation and a water resistant barrier. Partly the problems resulting from the complex relation between performance and technical solution will be overcome by the clustering of the demand for performances.

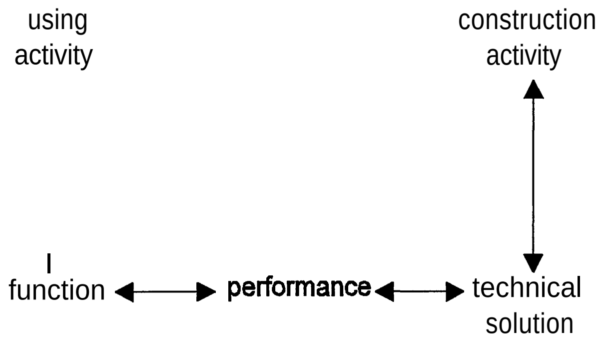

Fig. 8 Performance as measurable decision parameter between demand and supply
--------------------> choice determination process
<--------------------- cost allocation process

12. Clustering of demand in Open Building
Each function has its own demand period, which may result in a large range of demand periods. This may cause problems, because of the connection between performances, when they will be supplied by the same technical solutions. From the practical point of view I may be better to combine adaptation activities to diminish construction costs and the disturbance of he using process. Clustering can be based on the functions which are related to the same type of activity and by fitting the various individual demand periods into less numerous market demand periods.
An extreme example of clustering around activities is the demand definition for a hot house to be used as a laboratory. Since the experiment will last only seven years [27] the demand periods for space and for equipment will all be seven years (fig. 9).
Practice is, that decision makers are not aware of his clustering and as a result choose solutions which can last a much longer period and are bad from the sustainable point of view.

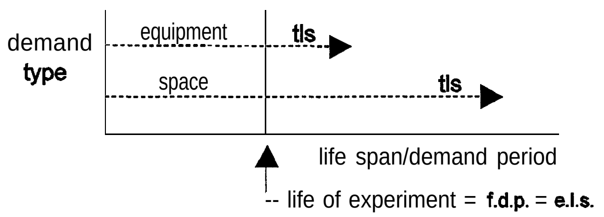

Fig.9 Clustering of demand around one activity (hothouse-laboratory-experiment)

More consequences has the clustering of demand for a bank office building [4]. The demand is split up in four parts: two concerning market demand for space and parcellation and two parts concerning the bank process. The letter two are connected to the technical bank process (safe and internal money transport) which will be defined for fifteen years and the period connected to the character of he interior of the bank (fig. 10). It is especially the last one, which results in high disposal costs over a very short period, of which he decision maker is not aware.

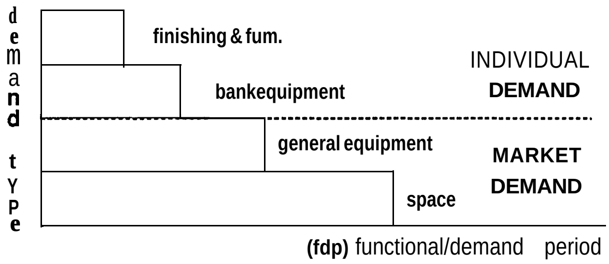

Fig. 10 Bank office building: a split up in individual demand and market demand to limit number of clusters maximise functional (market) demand period

An important consequence of the clustering in only a few demand periods is, that decisions about clusters do not have to be made at the same time and it is clear that only solutions which are related to different demand periods need attention as far as future disconnection is concerned.

13. Inadequate information concerning demand definition

To find technical solutions which will have minimised environmental consequences, we need information about activities and functions related to the primary process and to which are connected demand periods. A second important point is, that information concerning maintenance activities and disposal is lacking. As described in figure 11, most information is still lacking to have a really reliable demand definition and cost information to choose the adequate technical solutions [26].

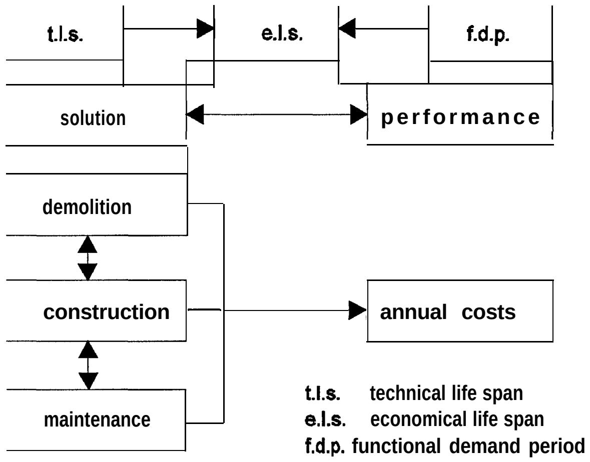

Fig. 11 Black boxes in information about performances and costs

14. Conclusion

In sustainable building focus it still too much on diminishing the consequences at the moment of (new) construction and at the moment of demolition. The period over which the technical solution has to be incorporated in decision making; incorporating the time parameter.

Taking time into account in fact is only possible when demand is defined properly. As a consequence, to maximise sustainability, decisions have to be taken on the basis of annual costs. In these costs all he environmental consequences have o be expressed. Sustainability is not an additional goal, but just economics, in which the environment is one of the cost parameters.
Since the various functions will be needed over different periods, the technical solutions have to be disconnected at different moments in time: Open Building is still actual. Only a disconnection scenario is needed, not a replacement scenario of the building.

References

1. Abma, T.J. (1997) Laat het formuleren van eisen te wensen over ? (in Dutch) M.Sc.-thesis, Eindhoven University of Technology, Eindhoven.
2. Batten, D.F. (1990) Built capital, networks of infrastructure and economic development. Proceedings CIB ***90, Building economics and construction management,*** Vol. 1, The building market, p. 2-5.
3. Becker, R. (1996) Implementation of the performance concept in building. Proceedings of the 3-rd ***International symposium on Applications of the performance concept in building,*** Tel-Aviv, Vo1.2, II 11-22.
4. Berben, P. (1987) Investing in bank office buildings. MSc-thesis, Eindhoven University of Technology.
5. Bon, R. (1993) The future of international construction: Secular patterns of growth and decline. In ***Habitat International,*** Vol. 17.
6. Brand, S. (1994) How buildings learn: what happens after they're built. Viking Penguin, New York, book review in *Environmental* ***Building News,*** 3(5), Brattleboro, VT.
7. Hermans, M.H. (1995) Deterioration characteristics of building components. Ph.D.-thesis, Eindhoven University of Technology, Eindhoven.
8. Hill,R.C., Bergman, J.C. and Bowen, P.A. (1994) A framework for the attainment of sustainable construction. ***Proceedings of the First International Conference on Sustainable Construction,*** Tampa, Florida, 6-9 November, pp. 13-25.
9. Hill, R.C. and Bowen, P.A. (1997) Sustainable construction: principles and a framework for attainment. ***Construction Management and Economics*** 15, pp. 223-239.
10. Hofmann (199 1) The Integration of Environmental Considerations into the Design Process: A Consulting Engineer looks at Daily Practice. ***Harmonisation Between Man and The Environment: Actions for the Profession,*** Tokyo, FIDIC.
11. Keoleian and Menerey, D. (1994) Sustainable development by design. ***Air and Waste, 44,*** May, 645-68.
12. Kibert, J.C. (1994) Establishing Principles and a Model for Sustainable Construction. ***Proceedings of First International Conference on Sustainable Construction.*** Tampa, Florida, 6-9 November, pp. 3-12.
13. Masters, L. (1984) ***Problems in Service Life Prediction of Building and Construction Materials].*** NATO ASI, 94.
14. Ruokolainen, A. (1996) The housing demands defined by needs and financial resources. Lic. thesis, University of Tampere.

15. Rutter, D.K. and Wyatt, D.P. (1994) Life Cost Management, A Search for an Environmentally Acceptable Balance between Conflicting Interests. *Proceedings **Strategies & Technologies for** Maintenance*. CIB W70 Tokyo. 1-8.
16. Switzer, J. (1967) The Economic Life of Buildings, ***RICS Conference Proceedings,*** Nottingham, RICS Library, London, pp 1-16.
17. Tempelmans Plat, H. (1982) Micro-economic analysis of the process of design, construction and operation of houses. In ***ZABSE Journal*** 14/82, pp. 1-14.
18. Tempelmans Plat, H. (1985) A financial basis for design participation. ***Proceedings of the international design participation conference Design Coalition Team,*** vol. 1, Eindhoven, pp. 169-188.
19. Tempelmans Plat, H. (1986) Realistic planning periods as a basis for design and construction decisions. ***Organisation of the design process.*** IABSE Workshop, Zurich, pp. 9-17.
20. Tempelmans Plat, H. (1991) Cost-optimal flexibility of housing supply. ***Management, economics and quality in building,*** E.&F.N. Spon, London.
21. Tempelmans Plat, H. (1993) Affordable housing in the long run. ***Proceedings of he 4th annual Rinker conference on building construction 'Affordable housing: present and future'***, University of Florida, Gainsville.
22. Tempelmans Plat, H. (1994a) Open building in developing countries. ***Urban development in developing countries,*** Eindhoven, pp. 209-217.
23. Tempelmans Plat, H. (1994b) Bruikbaar houden van het productiemiddel gebouw. ***Proceedings conference on** Integraal **Huisvestingsmanagement,*** Institute for International Research, Amsterdam (in Dutch).
24. Tempelmans Plat, H. (1995) Annual cost and property value calculation based on component level. Conference on Financial management of property and construction, Newcastle, Northern Ireland.
25. Tempelmans Plat, H. (1996,a) Property values and implications of refurbishment costs. ***Journal of Financial Management of Property and Construction,*** **Vol.** 1, University of Ulster, pp. 57-64.
26. Tempelmans Plat, H. (1996,b) Performance specification and cost calculation. ***Proceedings of** 3-rd **International Symposium on Applications of the performance concept in Building,*** Vol. 2, Tel-Aviv, pp. 6/25-32.
27. Vennegoor, J. and Tempelmans Plat, H. (1994) ***A system to** calculate office **space costs*** (in Dutch), Interface, Eindhoven University of Technology, 61 p.
28. Wyatt, D.P. (1994) Recycling and Serviceability: The Twin Approach to Securing Sustainable Construction. ***Proceedings of First International Conference on** Sustainable **Construction,*** Tampa Florida, 6-9 November, pp. 69-78.
29. Wyatt, D.P. and Gilleard, J.G. (1994) Deconstruction; an environmental response for construction sustainability. ***Proceedings of First** International **Conference on** Sustainable **Construction,*** Tampa, Florida, 6-9 November, pp. 113- 122.

An attempt to measure the unsustainability

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Abstract
As an expression of a legitimate need to become more responsible for the use of our present resources and the quality of our future life, Sustainable Development (SD) was, generally speaking, a favourable received concept. In spite of this it is still a matter in dispute, beginning with its denomination into Romanian and continuing with its definition and practical approach.

Taking into account the present situation of the society, which is faced with a difficult process of restructuring and the fact that there is not yet a global strategy of SD, it seems to be very convenient and useful to know where we are from this point of view. To give an appropriate measure of the development is itself an impressive work, but to measure non-performance or unsustainability could be seen as a venturesome attempt.

The Method of Evaluation the Sustainability Alteration Degree represents a proposed solution for such approach, which relies on a matrix composed by **82** rows (the descriptors of the build environment) and **19** columns (the factors of the natural environment and the social economic environment, including the sustainability criteria).

The main principle is the treating of the built environment both as a generator and a receiver of unsustainability in relationship with the other environmental components.

The paper contains some elements concerning the difficulties to adapt the principles of SD to the national context, some theoretical guides, the content of the method and its methodological aspects, its advantages and disadvantages, the results of two case studies and some conclusions.

The final idea is that the method is feasible and it is worth to improve it.
Keywords: built environment, criteria of sustainability, Romanian context, sustainability alteration, unsustainability evaluation.

1 Introduction

The concept of sustainable development (SD) is very familiar within the scientific community and on the top level of decision making from Romania.

We could also mention some progress recorded during last eight years which succeeded more or less in guiding the society in the right way, such as: the drawing of some global and sectorial strategies; the renewal of the legal system; the promotion of the research in the fields of energy conservation, protection and rehabilitation of the natural and built environment; the functioning of some governmental agencies and non-governmental organisations etc.

Nevertheless there are some factors which act upon the accuracy of SD assimilation.

One of them is the Romanian denomination of the concept ("dezvoltare durabilă") which was translated from French and does not express the strict meaning of the English corresponding.

The second is the ignoring of the possible difficulties to implement SD principle in a society, which experience a profound process of restructuring accompanied by a strong economic recession and very high social costs.

At last, the fact that there is not yet a national strategy of sustainable development generates some confusions and deviations.

In this context, the creation of a realistic basis for a suitable strategy could be seen as a project both necessary and opportune.

The papers summarise the results of such a project developed in the framework of Urbanproiect Institute, since 1996 [1].

2 Some conceptual guides

The research started with a review of the theoretical approaching of the SD in order to use the generally accepted meanings.

For instance, the notion of the built environment, which is frequently considered to be identical with human settlements, is found in the international documents [2] with the following definition:

> "The type which includes all the lands occupied by the houses, roads, mines, quarry, and other facilities together with the additional surfaces of intended use for human activities. Are included also, some types of open spaces which are closely related to these activities such as waste storage, vacant land, parks, urban gardens etc."

CIB-W82 Commission "Future Studies in Construction" [3] adopted the following definition for "sustainable construction":

> "The responsible design of a healthy built environment based a resource efficient use and ecological principles that can be responsibly created, managed, maintained and dismantled."

As concerns the structure of the environment as an entity, it was considered very convenient the global model launched on the occasion of the World Conference on the Environment, which took place in Stockholm, in1972. The issued document [4] presents the environment as a whole which embodies as the main components the natural environment and the anthropic environment. The last one includes the artificial environment and the socio-economic environment.

3 The existing practices

3.1 The external framework

The available references do not contain a model of indicators conceived to describe the unsustainability of the built environment.

However, studying the experience treasured in the other countries, we remarked some practices very interesting from the methodological pint of view, even if they were not suitable to our vision.

Such an example is the method of ecological quality of construction (QEC) from France [5]. It is applied to the new constructions and is based on some principles, which could be extended to the built environment (to save the natural resources; to reduce pollution; to integrate the buildings in the environment in harmonious way; to provide a healthy and comfortable life inside buildings).

The evaluation of the constructions eco-quality method (BREEAM) from Great Britain [6] introduces the idea to assign different scores to the solutions, which meet the high level of quality performances. It is applied to the buildings either new or existing.

Those 120 indicators of sustainable development recent published in Great Britain [7] were conceived in order to evaluate the dynamics of the English society development an to identify the tendencies which have to be adjusted in accordance with the SD exigencies. The indicators were based on the idea that the human activities induce some pressure upon the environment causing some changing with respect to the quality and the stock of natural resources the society in its turn act by policies and measures aiming to reduce this pressure.

In the Netherlands, the delivering of the National Plan for Environmental Policy [8] started with an analysis of the main components of the environment, most of them belonging to the built environment. They attached importance to the factors with a strong impact on the natural environment and the health of population. The specific indicators could be applied to evaluate the situation at one time, but some of them could measure its seriousness.

The model of the urban sustainable development indicators, which come from Norway [9], is interesting for the qualitative elements introduced beside the qualitative ones and also for the ethical signification attached to some indicators.

3.2 The internal framework

Although there are not a direct and unitary approach of the indicators concerning the sustainable development of the build environment, many existing models could be used as sources of useful data.

Thus the data periodically published by the National Commission of Statistics – NCS [10] give some information on the global and regional level, on the economic activities or parts (functions) of the human settlements. This data are more suitable for the qualitative evaluation, the qualitative elements being exceptionally introduced. Anyway those indicators are not intended to offer an integrated vision regarding the built environment state from SD point of view.

Others publications NCS [11] contain in addition some relevant data concerning the built environment (protected areas, the main economic activities with the strong impact on the environment, etc) and also some useful data to set up the comparison terms (e.g. the clearing surface versus afforestation surface which could point out the exceeding of the limits of absorption of negatives effects caused by cutting of).

The same source provides some information related to the environment protection expenditures, very useful for SD approaching.

On the occasion of some studies carried on in the framework of Urban Proiect, were defined and tested some indicators which deserve our attention.

Thus, the housing indicators [12] are interesting as they analyze the renovation and maintaining expenses, the land conversion rate and share of the dwellings of low comfort.

The prosperity indicator [13] on the counties represent an aggregation model of more indicators taking into account the hierarchy corresponding to the specific performances.

At last the quantitative and qualitative indicators aimed to define the sustainable city [14] are interesting as the intention but are disputable as the proposed optimum limits and the compatibility of all kinds of settlements.

4 The method to evaluate the unsustainability of the built environment

4.1 A way of understanding the reality

A holistic approach of the environment, which is counted as a basic principle for the application of SD concept, imposes the taking into account of its all defining components as well as the complex connections between them.

Consequently, the built environment is treated as a part of the whole environment having mutual relations with the other measure parts, i.e. the natural environments and socio-economic environments.

In relationship with them, the built environment works both as a generator and a receiver of the positive or negative effects from the point of view of SD.

In a certain context, sometimes appears more useful to know the weakness of the system then the high level of its records.

Along the same line, the approaching of the different parts of the environment is a conventional operation justified by the methodological reason. In fact they form an organic whole due to the human being - as individual and also as community - who is common factor acting like a blending element between them. That’s why the man must be found either in an explicit or in an implicit way in any evolution of the environment which respects the SD spirit.

This condition is the more so as, the whole society is in a critical state, meaning that the main features of sustainability are strongly altered and the given economic potential is situated under the level of requirements; such a situation imposes as a reasonable way to establish the urgent needs as an elementary stage before the allocation of the limited resources.

This is the situation of Romania, a country where the profound and so imperative process of restructuring and reform of the entire society, might involve some disorders and onerous costs hard to bear by a population which have already experienced a long period of restrictions and frustrations.

In this context, our research aimed to offer an instrument able to give a picture of the existing deviations against certain standards of normality in the sense deduced by the SD principles.

The proposed method was named The Method of Evolution the Sustainability Alteration Degree (MESAD which is MEGAD in Romanian). It was built on the idea that it is more profitable for the action to identify, first of all, the tender spots or vulnerability of the environment and also its proportions.

4.2 Method description

In order to analyse the built environment (BE) as a generator- through the instrumentality of human activity- of potentially negative effects upon the other components of the environment, i.e. man/society and the natural environment, which could be found within its impact field, it has been used as a working scheme a matrix constituted as follows:

* On the first horizontal row are figured the constituent elements of the BE or the factors that generally correspond to the functions by it. They are: achieved land use; dwellings; transports; water supply; sewage; industry; culture; education; health; public institutions and services; trade; tourism; services; parks; waste.

Each of the 15 factors of the environment is detailed by means of several specific indicators selected as function of their capacity to induce effects altering the sustainability of the other components of the environment. These indicators may characterise the size, the structure or the quality of the factors to which they refer. For instance, among the indicators for dwellings are to be found: dwellings in stock, weight of sick dwellings; average number of persons/room. The total number of these indicators is of 82.

* Vertically are introduced the other environment factors located within the impact field of the BE, i.e. : man and/or society, vital resources and the natural environment.

The detailed vital resources are grouped in primary and secondary resources. The first category comprises renewable (solar energy, rain water, wind energy, forests) and non-renewable resources (oil, coal, natural gas, minerals, soil). The second category comprises: energy and building materials with major impact upon the environment (limestone, aggregates, wood, cement, coatings, etc.). The natural environment is described by its factors, i.e. : climate, relief, air, water, soil, vegetation, fauna. The total number of columns is 19.

* The reciprocal causality analysis between the two co-ordinates is achieved by means of auxiliary elements, as for instance the reference terms, with which the performances of each indicator of the BE is compared. Those reference terms generally represent quantitatively expressed levels , but under given circumstances may be expressed as ‘existence’ or ‘non-existence’ of an important characteristic of the BE.

For instance, in the case of bad maintained dwellings, the reference term is of 50% from the total, but for unsafe dwellings, as low as their percentage might be, the situation is estimated as risky and therefore the reference term is the ‘non-existence’.

* Other auxiliary elements are: the list of phenomena liable to induce effects altering the sustainability (climatic changes, landscape modification, reduction of the ozone layer, pressure upon the agricultural land, increase of the transport distance, poverty, dependency, etc.); the list of sustainability characteristics for man and/or society accompanied by importance marks awarded on a scale from 1 to 5 (health/5, comfort/4, tollerance/3, equity/2, altruism/l etc.); the list of sustainabibility characteristics for resources, also accompanied by importance marks (efficient use of non renewable resources/4; rehabilitation of land/3, etc.); the list of sustainability characteristics and of the importance marks for the natural environment (climatic stability/5; bio-diversity/$ aesthetic value/3, etc.).

The four lists are abbreviated named: List A, List B, List C and List D and comprise receptively 32, 24, 11 and 10 positions.

4.3 **Application methodology**

Applying MEGAD presumes going through the following stages:

1. Establishing a comparison base
2. Measuring of the vulnerability indicators (VI)
3. Interpretation of the results

* In fact, the comparison base represents a summation of the effects or indicators liable to alter sustainability characteristics, or of the ‘black points’ dispersed by the action of diverse factors of the BE.

This sum may be calculated in two ways: as a simple summation of the identified effects, or as the weighted summation taking into account the importance marks awarded to the sustainability characteristics.

For instance, the exceeding of a certain limit (reference term) of the urban surface/inhabitant may generate 3 5 alteration effects, that representing a score of 140 points if the importance marks of the affected sustainability characteristics are taken into account.

Under the assumption that all the possible negative effects of all the 82 indicators of the BE occur, a score 1413 will result, respectively 4766 ‘black points’ which constitute the primary elements for characterising each case apart.

The ratio of 3: 1 between the two sums indicates the degree of implication in the alteration process of the primordial sustainability characteristics (bio-diversity, health, efficient use of resources, etc.) which are rated with maximal importance marks (5 or 4).

* The vulnerability indicators are determined as percentage after the identification by means of the same scheme of all the effects altering the sustainability of the analysed system, in the proposed two variants, as against the initially scores.

For the situation in which the BE is considered as the receiver of sustainability altering effects generated by the other components of the environment, the following hypothesis have been chosen: 1) area with increased disaster risk; 2) area with degraded waters; 3) area with forests strongly affected by the drying up phenomenon; 4) geographically, demographically, economically, socially desadvanteged.

Each of the 4 situations corresponds to an increase with 0.5 points of the sustainability alteration indicators multiplication coefficient. So, the ratio between the indicators corresponding to the comparison base, may increase, for example, from 3 to 5.

* The results obtained on base of the analysis scheme proposed by MEGAD contain at each moment useful information for decision makers.

So, the sum of alteration effects in its first variant indicates in fact the number of problems that require solutions in order to stop the sustainability altering phenomenon. The indicators, adjusted by means of importance marks, indicate how serious the situation at a given moment is in what concerns the sustainability of the analysed system.

This information may be useful both for establishing the objectives of SD, and for rating the action priorities.

For instance, if the sustainability of a system is menaced, especially by the action of industrial agents, the aim will be to balance the efforts between the pollution reduction at the source and the rehabilitation of the affected factors.

On the other hand, in case the domestic waste constitutes an obvious pollution source, but on the other side unsafe buildings, endangering the safety of people exist, the efforts for strengthening the latter should not be diminished or neglected, in order to radically solve the problem of domestic waste.

The lower or higher vulnerability of the BE, considered from the point of view of the SD requirements, must be treated as a motivation for action, understood as improvements of the sustainability degree by reducing or eliminating alteration effects and not as elimination of unsustainability sources, which is practically non feasible.

5 Case studies

Till now, the verification of MEGAD has been performed on the example of two towns of the group of major cities (with over 300.000 inhabitants). They are individualised by the following characteristics:

CONSTANTA

- historical town erected on the site of an ancient Greek citadel
- the main harbour at the Black Sea, tax free zone
- surface: 5942 ha
- population density: 5866 inh./km^2

IASI

- ancient historic and cultural centre in the east of the country
- important node for political and economical relations with neighbouring countries in the east
- surface: 3 560 ha

population density: 9675 inh./km^2

The sustainability alteration indicators established by MEGAD have been 690 ‘black points’ for Constanta and 763 for Iasi. After being adjusted with the importance marks, these sums became 2503 and 2955 respectively, which correspond to vulnerability indicators exceeding, as a rule, 50%.

The multiplication coefficients of the alteration degree are 3,6 and 3,8 respectively, which is explained by the high weight of important sustainability characteristics which are already under the impact of different alteration phenomena.

More than that, the two cities display the following characteristics:

CONSTANTA	IASI
• area with a significant disaster risk • area with stream ways affected by pollution and with highly pollution vulnerable ground water	• area with high disaster risk • low quality stream ways (III-rd category) • woods severely affected by drying out phenomenon

Consequently, the multiplication coefficients will increase with 1, respectively 1.5 points, that means they will become equal to 4.6 and 5,3 respectively.

Testing the method on the two specific cases proved to be very useful, because it confirmed its logic and signalled some of its shortcomings in what concerns the way some environment factors are characterised, as well as in what concerns some units and some reference levels used.

It permitted also to draw some conclusions concerning the access to primary data and the possibility of independent (non-assisted) use of the method.

6 **Conclusions**

From the point of view of the SD, the assessment of the BE state is capital for deciding upon the necessary measures and for rating their priorities, especially under the circumstances of limited resources. Such an analysis is very useful for preparing orientation documents for the development, such as:

- long term strategies for the development of the BE, irrespective of its size
- urban and territorial planning development plans

The most important advantages of the MECAD are:

- it addresses the BE as a constituent part of a living whole, who's components are in reciprocal causality relationship
- the BE is treated both as a generator and as a receiver of sustainability alteration effects
- it permits to aggregate very heterogeneous, both by origin as by impact area, elements
- the identification of the most risky unsustainability sources becomes possible by computation of certain vulnerability levels
- the fact that vulnerability is established as compared with sustainability criteria and not related to a specific case permits a more accurate assessment of the existent situation because the idea of competition brings in front more readily the achievements than the failures
- has an open character because it permits the adjustment or replacement of some elements, such as the indicators characterising the BE, the characteristics of sustainability, the sustainability altering phenomena.

As disadvantages are to be quoted:

- the great volume of primary data and the difficulties to obtain them
- the subjective elements it contains (importance marks, sustainability criteria) which might induce a certain caution concerning the exactness of the method

- the need of special skills and competence as multi-criteria1 analysis capacity, method, lack of prejudices
- the great number of required verifications, and, probably the need of adaptation in order to be applied to other categories of towns (medium cities, little towns, villages)

As a final conclusion, MEGAD may be considered as a feasible method which deserves to be developed for the role it may play in promoting the SD in our country, which substantiates the necessity of pursuing the research in **1998.**

REFERENCES

1. Şuler, J. **(1997)** *The relationship between the sustainable development and the built environment,* Bucharest.

2. UN HABITAT **(1995)** *Global Raport on Human Settlements.Statistical annex, New* York.

3. CIB-W82 **(1995)** *The Proceedings of the 18th CIB- W82Commission Meeting,* Ascot.

4. x x x **(1972)** *Declarația asupra mediului,* Stockholm.

5. x x x **(1996)** *Mieux Batir avec l 'Envirounement,* Paris.

6. Baldwin, R. **(1996)** *Environmental Assessement and Management Buildings, CIB-W82 Meeting,* Bucharest.

7. Department of the Environment **(1996)** *Indicators of Sustainable Development for the* UK, London.

8. Lanting, R. **(1996)** *Sustainable Construction in Netherlands. A perspective to* **2010,** *CIB- W82 Meeting,* Sophia Antipolis.

9. Naess, P. **(1996)** *Criteria and indicators of a sustainable urban development,* Oslo.

10. *NCS* **(1995)** *Statistical Yearbook of Romania,* Bucharest.

11. *NCS* **(1993)** *Statistics of the Environment,* Bucharest.

12 Budigteanu, I. **(1995)** *Housing indicators,* Bucharest.

13 Şuler, J. **(1996)** *Urban land market structuring,* Bucharest.

14 Pascariu, *G.* **(1994)** *Methodological framework for sustainable development of the human settlements,* Bucharest.

Necessity of common understanding of sustainability in construction in Asia

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Abstract
From the end of this century to the beginning of next century, a quite big construction boom is expected to occur in Asia for the development of the countries in that region. This boom will be considered so big that major world construction market will be shifted to Asia.

The Third Conference of Parties to the U. N. Framework Convention on Climate Change (Kyoto CP03) was held at Kyoto on December 1997. According to the Kyoto Protocol developing countries are exempt from new commitments to mitigation of global warming. Rapid development together with the conclusion of Kyoto CP03 may have a great influence on the global environment.

One of the key issues to avoid such kind of problem is to let people understood the importance of sustainability for environment who will be involved in execution of the construction projects for development. However, almost all people of developing countries considered that development means industrialization and urban development, which in a sense developed countries experienced during development of their countries. Moreover, the typical examples of Asian developing models are Japanese, Korean and Taiwanese model. Scarcely these model did give careful consideration to the global environment. They only studied local problems of environment.

However, in the discussion of sustainability of construction there is quite big gaps of opinions of the people between developing countries and developed countries. Therefore, establishing clear and common concept of sustainability will be indispensable to maintain good global environment for future generation of the world.
Keywords: Asia, construction management, development, global environment, growth of economy, professionalism, sustainable construction

1 Introduction

Recently many countries in Asia are suffering from financial crisis which originated from Thailand in the middle of 1997. Certainly, this situation will slow down, in some extend, the speed of development of many countries in Asia. However, it does not mean that the world center of development from the end of this century to the beginning of next century is shifted to any other place than Asia.

On the contrary, the fact that the financial crisis of Thailand have a great influence on the world economy shows that the increase of importance of economy of Thailand in the world. Towards 21 century, Asia will become the dominant region of the world economy.

Today, in Kuala Lumpur, Malaysia, there is the new tallest building in the world. Although there is some argument that Sears Tower in Chicago is still the world tallest building, without doubt it is a symbol for the progress made in Asia. This progress and momentum will be remarkable sea changes not only in the economy in Asia but also of the world. In this progress, Asian are going to create their own rule for development.

As a well known sociologist pointed out, "what is happening in Asia is the most important in the world today. Nothing else come close, not only for Asians, but for the entire planet. The modernization of Asia will forever reshape the world as we move toward the next millennium." He also predicted that this modernization will be done not as Westernization but rather Asianization.[1] Therefore, the development in Asia by Asianization will give some impact to the whole world in many aspects in the next century. Among them, the most important issue for future of the world should be the relationship between development in Asia and its influence on the world environment.

Before discussing this relationship, concept of development and its mechanism should be clarified. The definition of previous development should be analyzed to adjust for sustainable development in the future.

Also, civil engineers have taken big roles for these development. Especially the system and methods of "construction management" in civil engineering originated in U. K. and developed in U.S.A. have been and will be used for the execution of many projects for development such as construction of infrastructure. From this point of view, a key to this problem is depending on both how "construction management" is handling the environment of the world and what kind of concept to the world environment civil engineers have in execution of actual projects for development.

In 20^{th} century, there were many wars in the world, through experiences of these wars, people of the world, especially, in Asia consider that most important thing for the people and country should be economy rather than military force of the country. But this concept should be checked from view point of the world environment.

Coming 21^{st} century should be a challenging era fur human being whether new philosophy will be established for maintain the environment level of the world in the level of as it have been.

From this point of view, the result of The Third Conference of Parties to the U. N. Framework Convention on Climate Change (Kyoto CP03) held at Kyoto on December 1997 is quite important as the starting point towards 2 1^{st} century to make a consensus of the people in the world to establish rather new philosophy for world environment.

There is a quite big question in the Kyoto Protocol which exempt developing countries from new commitments to mitigation of global warming.

2 Present mechanism of development

2.1 The meaning and measurement of development

Nowadays, it is a common sense of the people of Asian developing countries that a major goal of poor countries to escape from poverty is economic development or economic growth. This concept is supported by Japan's experience of rapid modemization in previous half century. During the second world war, almost all of Japan's manufacturing base was destroyed by air raid of U.S. air force into ashes. As a result, approximate half of workforce of Japan worked in agricultural sector. At that time Japanese average income was quite small and ranked below those of many developing countries.[2] Much has been changed since then. Japan with small mountainous land without any natural resources has become a highly developed country challenging American leadership in a number of industries. Also, the group of NIEs (South Korea, Taiwan, Hong Kong and Singapore) is showing the most successful economies in the world. These are the typical example of Asian miracle pointed out by world bank report in 1993. Keywords for this progress of these countries are "development" and "growth of the economy".[3]

However, these two terms are not identical in the strict sense of terms. Economic development is linked with economic growth accompanied by some changes in output distribution and economic structure of the country.

Also, measurement of economic development is quite important to know actual state of the country. For this purpose, usually two indices are used. One index shows the rate of development and the other shows the level of development. The rate of development indicates developing speed and it is explained by using growth rate of economy which is computed in the form of annual change of GNP per capita after adjustment by price deflator. On the other hand the level of development is measured by using the figure of annual GNP per capita which usually used for classification of countries. One classification used by World Bank divides all countries into three categories by using GNP per capita. According to this classification, in 1993, three categories were *low-income countries* (less *than* $700), *middle-income* countries ($700 ～12,000), and *high-income* countries (more than $12,000). [3]

Today an increasing number of the high and upper-middle-income countries are non-Western, and fastest-growing countries are among countries in Asia and not necessarily those of with the highest GNP per capita. Usually the countries with higher GNP show the less growth rate of economy.

It is quite natural for developing countries to make their best effort to pull up their rank in the classification by income level.

2.2 Principle and concept of development

It is quite remarkable thing that there are three countries and area in Asia among high - income economies, Japan, Singapore and Hong Kong. Especially Singapore and Hong Kong surpassed or almost surpassed United Kingdom which was their suzerain country. Thus, growth rate of economy of NICs are quite high . This means that developing speed of the countries in NICs is quite high .[3]

This fact produce some expectation to other developing countries in Asia so strongly that for the development of the country industrialization is most effective way and principle and concept of development of the country cannot be discussed without industrialization. Many people in Asia consider that development of the country can be done by economic modernization by industrialization.

2.3 Economic modernization in Eastern world

2.3.1 Capitalism as a key to economic growth in Western world

To begin with, it is necessary to know the origin of the economic growth. What did make sustained economic growth? In the history of Western world capitalism made it. Capitalism is the economic system dominated in Western world since the breakup of feudalism from the fifteenth to the eighteenth centuries. In principle, capitalism is the economic system of relation between private owners and workers. Pieces of land, mines, factories, and other forms of capital as means of production are privately held and workers who were free but without any capital sell their labor to employers.[2]

Capitalism, as an engineer for rapid economic growth, spread beyond Europe to the outposts of Western civilization. And capitalism is most suitable system for industrialization. In Eastern countries there have been some barriers to capitalism not only in traditional societies but also in effect of colonization by Western countries. It is clear that most of Asian countries are lacking the strong capitalists and the effective bureaucratic and political leadership which are essential for rapid economic modernization. [2]

2.3.2 The Japanese developing model

Japan is one of rare exception of the country of modern economic growth in non-Western countries. Japan's economic developing level was much lower than Western countries before the Meiji revolution in 1868. After Meiji revolution Japan's "guided capitalism" to catch up Western civilization by its government initiated large investments in infrastructure which helped domestic industries to export their product overseas and also borrow abroad.[2]

Japan was devastated economically during the second world war. In the late 1940s and beginning of 1950s, technical and economic assistance from U.S. like the Marshal Plan made it possible to reorganize international trade system and financial system as well which provide the basis of creating economic miracle.

It is obvious that the remarkable rapid growth of Japan occurred because technical knowledge and human capital were intact, even in ruins of other capitals by war.[2]

2.3.3 Development of Asian Tigers

The fastest developing countries in the world now are the countries called Asian Tigers. In other words they are called NICs as mentioned before: South Korea, Taiwan, Singapore and Hong Kong which became the part of main land China after middle of 1997.But Singapore and Hong Kong are only small city states doing business mainly in the field of trade and finance. Therefore. rapid development of these city states are associated with development of their neighboring country. For Hong Kong there is developing main land of China. In the case of Singapore there are developing Malaysia and Indonesia. Only Taiwan and South Korea are the countries which experienced quite high rate of growth through the years at the end of this century.

The models of development of these two countries are almost same as that of Japan. Similar to Japan, Their governments systematically intervened to invest to construction of infrastructure for further development of the countries and promote export their products and education for better human capital under the political and economic stability. Also, these two countries like Japan, had a high quality of their own management backed up by ancient Chinese philosophy of Confucianism.[1]

2.3.4. Lessons from non-Western models

Due to the collapse of the Soviet communism only few countries such as North Korea and Cuba stay with the Russian model of economy. For many Asian developing countries including Vietnam after their "doi moi" Japanese, Taiwanese and Korean models are quite attractive for developing their countries because these three countries are not democratic in the Western sense with Eastern tradition which many developing countries have in common. These models were effective at past. However, there is a big possibility that they will bring big problems of global environment in the future.

2.4 Infrastructure for development

2.4.1 Infrastructure as a key to development

As has been mentioned, in the models of fast developed countries in Asia investment to infrastructure is one of the most dominant factor for economic growth. Good infrastructure raises productivity and lowers production cost.

The precise linkages between infrastructure and development are still open to debate. However, infrastructure capacity grows step for step with economic output ; a 1 percent increase in the stock of infrastructure is associated with a I percent of increase in domestic product (GDP) across all countries.[4]

2.4.2 What is infrastructure

Usually infrastructure is divided into three categories by World Bank [4]: public utilities, public works and other transport sectors. Public utilities are consist of power, telecommunication, piped water supply, sanitation and sewerage, solid waste collection and disposal, and piped gas. Public works are including roads and major dam and canal works for irrigation and drainage. Also, other transport sector means urban and interurban railways, urban transport, port and waterways and airport.

Infrastructure is an umbrella term for many activities referred to as “social overhead capital” by many development economist. [4]

2.4.3 Efficiency of Infrastructure

Infrastructure can deliver major benefits in economic growth, but only when it provides services that respond to effective demand and does so efficiently. Service is a goal and the measure of development in infrastructure. Major investments have been made in infrastructure stocks, but in too many developing countries these assets are not generating the quantity or the quality of services demanded. Cost of this waste are high and unacceptable. The causes of past poor performance, and source of improved performance lie in the incentives facing providers.

3 Roles and concept of construction management

3.1 Effective execution of the projects of infrastructure

World bank report [4] says that infrastructure has a high potential payoff in term of economic growth. However, infrastructure alone does not guarantee growth of economy. There are many infrastructure which have smaller return on investment. The disparity in return on investment may be due to the differences in the efficiency of investment across countries.

3.2 Construction management as a tool for effective implementation of projects

As the report of world bank [4] mentioned the efficiency of infrastructure is indispensable. For this purpose, system and methods of "project management" and "construction management " has been developed and used in the execution of actual projects. However, the efficiency of infrastructure mentioned above are efficiency from view point of economy. There is no consideration in construction management on environment. There are so many text books on "construction management" published in U.S.A but there is no indication about global environment in them.[5]

Modem theory of construction management only written on the basis of economic efficiency. Economic efficiency dose not meet with global environment.

3.3 Basic concept of construction management

Modem theory of construction management is aiming the efficiency in economy. Actual approach to this is divided into two aspects; efficiency in performance of project, and efficiency in construction works. Efficiency in performance of project should be checked by the feasibility study of project in planning stage. Efficiency in construction works are analyzed by time, quality and cost. However, only few projects checked by assessment of local environment, but not that of global environment.

4 Paradigm shift required for sustainable development in Asia

4.1 Are economic growth and development worthwhile?

By economic growth the range of choice for human being has been widen in one way. But at the same time, it brings a quite big restraint for the activity of human being by changing environment of the world. Even before environment problems caused by economic growth were pointed, economic development and growth have both costs and benefit. There are many people who considered that the widen range of choice brought by economic development and growth does not link directly to happiness of the people because happiness is depending one the balance between wants and resources. Moreover, the serious cost overlooked before is environment of the world.

4.2 Influence of development on global environment

World bank report [3] shows that energy consumption per capita equivalent to kilograms of oil will increase proportionally to GNP per capita. This mean that rapid development of countries in Asia causes big amount of consumption of oil resulting in emission of green gases discussed on Kyoto conference.

There is well-known theory of relationship between economic index and environment index by Kuznets.[6] In this old theory environment will be improved after the income level reach to certain level. Application of this theory may be limited to environment problems in the country but not for the global level. And also this theory itself has been denied by some people.[7]

4.3 Report from Maldives

Development of countries in Asia will make a big influence to the global environment. But more direct influences on the region of Asia is predicted and discussed on the conference in Maldives in 1997. Among them are diminishing area of tundra in Siberia, drought in Mongol, more smog at big cities in Japan, break out of heat waves and epidemic disease in Thailand, Myanmer Bangladesh, increase of flooded area due to rise of sea water level in South China and Japan, and diminishing of tropical rain forest in Thailand, Laos, Vietnam and Cambodia

4.4 Required changes of concept

4.4.1 Small is beautiful

First of all, it is necessary to consider whether development or growth of economy is important for human being. There have been several people who considered this problem in the deferent way like Mahatma Gandhi, nonviolent politician and leader of nationalist of India. He advocated of small scale of development taking harmony with nature and reduction of materials want. For him, humane means for development were as important as appropriate end. [2]

4.4.2 Development

Gandhi's vision has inspired many people and has been followed by Schumacher, British economist who believed that productive activity should be judged holistically including environment as well as its simple economic ends.[2]

Also, it is easier for Asian people to understand and follow Gandhi's principle. Therefore, the review of the existing concept of development should be done from such kind of view point and establish rather new concept for development..

4.4.3 Construction management

Theory and practice of the "construction management" is only one general and effective method which will solve problems of global environment in construction. Of course, there is some special field to handle environment hazard prevention in civil engineering, but construction management handle projects for development as a whole. Also, projects for development should be reviewed in every stages of execution of projects under the light of global environment. For this purpose, necessary amendment should be done in existing system and methods of "construction management".

5 Effective measure to be taken

5.1 Political aspect

Same as Kyoto conference, some political international conferences are indispensable where total problems of global environment will be discuss to establish legally binding targets for saving global environment. In addition to them, every effort should be done for global environment using other political and economical systems such as OECD ODA and even Technology Transfer.

5.2 Civil Engineers' professionalism

There is well-known official register of the American society of civil engineers which defines and amplified "profession" of civil engineers.[6] In this register, there is no indication about global environment. It might be quite effective if this register will be amended to focus to the problems of global environment.

5.3 Necessary amendment in "construction management"

The time has just come when to avoid possible blaming civil engineers for destroying nature and environment, it is necessary to establish new concept of construction management for saving environment. In that new theory the performance of the projects as a whole should be checked from view points of global environment. After that each stage of project execution checked as well. By this necessary amendment civil engineers become a deity instead of notorious destroyer of the nature.

6 Conclusion

From the end of this century to the beginning of next century, tremendous amount of construction projects of infrastructure will be carried out in the region of Asia. These construction projects will effect so much to the world environment that some counter measure should be needed. There is quite strong linkage of the concept of Asian people among happiness of human being, poverty, development, growth of economy, infrastructure, and construction project. Concept of environment is out of this linkage. This tendency should be changed and common understanding of sustainability in construction will be needed to keep global environment for the coming next generation of human being. For this purpose, system and methods of "construction management" should be reviewed to put concept of environment into its theory as most important principle. Also, professionalism of civil engineers should be also revised in order to put the concept of environment into its fundamental philosophy.

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8 References

1. Naisbitt, J. (1996) *Megatrends Asia,* Nicholas Brealey Publishing Limited, London
2. Nafziger, E. W. (1997) *The Economics of Developing Countries, 3rd Ed.,* Prentice-hall, Inc. New Jersey
3. World Bank (1995) *World Development Report 1995,* Oxford University Press
4. World Bank (1994) *World Development Report 1994,* Oxford University Press
5. Barrie, D.S. and Paulson B. *C.* (1992) *Professional Construction Management, 3rd* Ed., McGraw-Hill, New York
6. Kuznets,S(1955) Economic Growth and Income Inequality, *the American Economic Review, 45* (1) pp. 1-27
7. Matuoka, S., Matumoto.R. and Kawauchi,. I.(1997) Relationship between Economic Growth and Environmental Problem in Developing Countries- Is Kuznets' Curve to be Applicable?-- *Proceed of the 8th Annual Conference of the Japan Society for International Development,* Urawa, Japan

Taking into account environmental values in building construction

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Abstract
The article deals with the improvement of environmental management in the building sector looked from the viewpoint of the building market needs. The base for the article is the method for calculating ecological balances of buildings created in the Institute of Construction Economics and Management of Tampere University of Technology. It has been used to assess the impacts of building construction and creating it has brought experiences in the assessment of environmental impacts.

In design, acquisition and use of buildings, understanding of ecological interrelations cannot be expected of the building sector experts and clients. So that the market mechanism on the ecological building market can function, it is important that the ecological quality of a building can be proved reliably to the client. Unambiguous ways to verify the quality levels are therefore needed for the sector. These unambiguous and simply to use indicators should cover a significant part of the environmental impacts of building construction. This will turn out to be to the whole building sector's benefit. The operational implementing organisation gets clear development targets and the clients can buy the quality they want.

The total impact of buildings must be considered in the strategic development work and in the improvement of the lines of action of the market. In that case, the typical environmental loads connected with the construction, maintenance, use and demolition must be understood. The calculation method for ecological balances of buildings used in this study is one way of assessing the impacts of whole buildings. Models like this are based on information collected from production plants and literary sources. The models are well suitable for showing the improvement needs and for supporting development work. Instead of that, it is difficult to verify the quality of a building to be sold with these models. The essential choices to be made in the building design causing environmental impacts can be found by using a total model. It seems probable that the development according to the mere purchase decisions of clients is not enough for reaching the sustainable level of environmental impacts. So to transfer the costs of external impacts to those generating them is an additionally needed way of market control. In that case the non-material inputs which are normally left outside the assessment of environmental impacts are taken rightfully into consideration.
Keywords: Ecological balances, sustainable construction, input-output analysis

1 Introduction

For the time being, the building sector is dealing with the question of how to considerably reduce the environmental impacts associated with the production, maintenance, use and demolition of buildings. Several procedures have been and are being developed this very moment for the assessment and control of impacts.

This article deals with the problem of controlling environmental impacts. The problem is crucially associated with the research where the method for calculating ecological balances has been created. The basis of this research has been the research traditions of the Institute of Construction Economics and Management of Tampere University of Technology (TUT). The TUT has studied extensively the design management of buildings which comes from customer activities and pays attention to customer needs (e.g. [1],[10],[11]). In addition to this, the structure and markets of the building sector and its importance to the Finnish economy have been studied in TUT by using the input-output analysis (e.g. [6]). Also studies on the environmental and energy economics of buildings have been done (e.g. [2],[7], [S]). Environmental impacts of building construction and their reduction have been examined on this basis. This article presents aspects that became known in the research.

2 Consideration of Environmental Values in Building Construction

2.1 Environmental impacts of buildings and building markets

A method for calculating ecological balances of buildings has been created in the Institute of Construction Economics and Management of Tampere University of Technology [3],[4],[5]. It can be used to calculate the natural resources used in buildings and emissions and waste originating from them. In the model, the environmental impacts of building materials production have been calculated with an input-output analysis where the input-output table of the national economy has been completed with information on the production processes of building materials. Building materials used on the site are composed of industrial products and services which are needed for transporting them to the site. Building components and buildings are composed of building materials. The present files in the model enable to estimate the energy amount used for building construction, central emissions causing global warming and acidification as well as waste in construction and industry.

A typical Finnish residential multi-storey building has been analysed with the model. Figure 1 shows some environmental effects from the production and use of this residential building made of concrete elements. Diagrams show that the development of residential buildings should be improvement of both technical and operational factors. With technically better solutions it is possible to have influence on most impacts. It is quite clear, however, that the quantity of dumping waste and energy consumption can be reduced significantly by guiding and facilitating building user functions. It can also clearly be seen that in building design there can be found very important decisions concerning the total amount of environmental impacts and, on the other hand, quite unimportant choices.

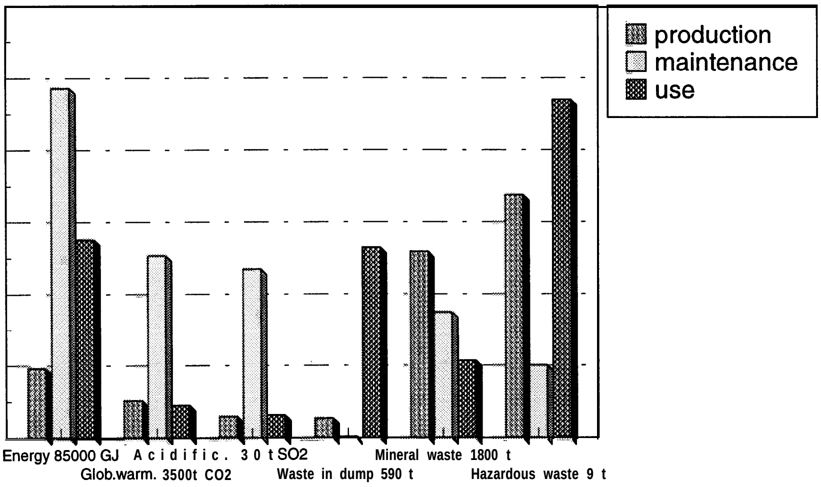

Figure 1. Environmental impacts of a typical Finnish residential building (appr. 4 500 m³) during 50 years of use. Function includes calculation of electricity consumption and waste amount of typical families.

The aim of ecological building construction is to reduce environmental loads. In addition to the environmental impacts shown in Figure 1, several other environmental impacts are related to buildings and their use and should be identified in future. However, identification of environmental impacts is not enough. It is just as important to find the decisions and choices which make it possible to reduce environmental impacts.

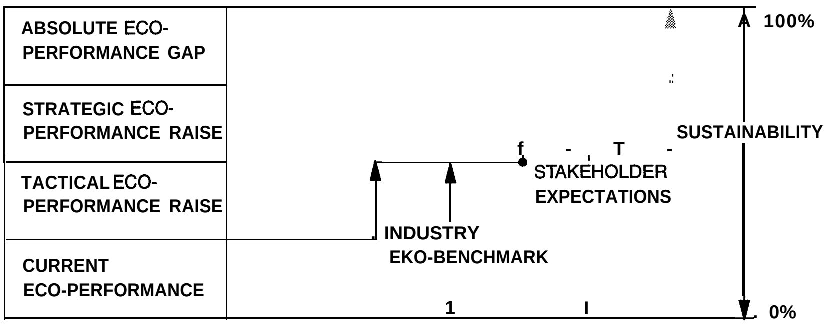

Figure 2. Development of eco-performance in business ([8], converted).

Implementing sustainable development shall for the most part be carried out by the markets. Therefore, decision-making on the market shall be studied in order to find tools for a real reduction in environmental impacts. Figure 2 shows a simple model of the development goals of products on the market. According to it, the tactical rise of eco-performance takes place within operational goals. They are simple target values, e.g. own environmental impacts compared with those of the competitors. In strategic development, one tries to identify customer needs, market development and in general the defects in environmental issues control. On the basis of detected possibilities and threats products are being developed according to needs. Purchase decisions only are not leading the building sector directly towards sustainability so the society should tend to affect with its decisions on the way that the eco-performance gap is as low as possible.

2.2 Operational development

In order to maintain the present competitiveness, the enterprises should try to take care of a sufficient competitiveness compared with that of competitors. Operation can be improved remarkably already with some benchmarks on the level of practical design. Energy consumption can be affected by decisions concerning among other things casing, heating and ventilation of a building. Indoor climate is affected among other things by ventilation and emissions from surface materials into the indoor air. To reach the goals of the operational level can neither require understanding of complex evaluation methods nor complicated calculations. All experts in the building sector cannot be specialists in solving environmental problems. To the operations model of a building project should be added clear operational target values for decisions in which a significant part of the environmental impacts of a building are determined. From the standpoint of a building process, control of environmental impacts should be started in the earliest possible stage. The chance to influence is best in decisions on large entities. The clear operations models of the operational level are important, because on this level the impacts are being determined continuously.

It is very useful to the building construction clients if the decision on the purchase of a house can be based on very simple assessment criteria. In addition to simplicity, the assessment criteria have to be reliable and widely accepted. Building owners need to be able to prove the environmental criteria further to their customers.

2.3 Strategic development

The aim of the strategic development is to create products competitive on the future market. The threats and chances of building construction and possession of buildings can be identified only by studying buildings as operational entities. Then it is possible to notice the most important environmental impacts associated with production, maintenance, use and demolition. Concerning strategic development, all significant environmental impacts are risks to business activities. Rise in productional inputs can be seen directly in production costs. Customers are interested in how they can meet future challenges in their buildings. If customer needs during using time have not been taken into account, the attraction of buildings will become weaker.

The results of strategic development shall be transferred to a part of the practical construction. As we stated earlier, development in the implementing organisation can be carried out only based on simple lines of action. Therefore we have to identify the design decisions in which the coming environmental impacts are really being affected. Impacts need to be interfered in the earliest possible design stage. Even a good building shall be sold to the customer. Reducing environmental impacts is not that kind of quality customers could identify directly in the end product. It is very difficult for a single enterprise to create a generally accepted model for assessing the environmental quality of products. The procedures applicable to the assessment can be worked out best in collaboration inside the building and real estate sectors.

2.4 Development of market procedures

It is very important to the building sector market that supply and demand meet. The building sector has to produce such buildings the real estate sector and building users need. The real estate sector and the users have to be able to identify the quality of buildings. Rules of the game for the building sector can be worked out by the building and real estate sectors themselves. Society can control the markets wider e.g. by directing the costs of harmful impacts to those generating them. In some cases also restrictions and prohibitions are well-grounded.

Understanding the economic decisions on the market is a prerequisite when influencing market operation. At the same time it is easier to understand the importance of different measures. In Figure 3, this basis of decision-making has been examined a little closer. Many people are ready to give up something of their financial well-being if they can affect the state of the environment. Consumers acquire those commodities which, examined in the decision-making, bring the biggest benefit compared to used inputs. If consumers regard environmental or social values as important in the short or long term, they tend to take them into account as much as possible when making choices. In principle, natural resources conservation and restriction of emissions could stay on a level consumers on the average want. In practice, markets alone do not deliver sustainable solutions. Consumers' will to give up something of personal comfort for the nature and coming generations does not correspond to the level required by the nature. On the other hand, market activities are restricted by several factors like incomplete competition, insufficient knowledge of products and their impacts, externalities as well as insufficiently specified ownership. These factors cause that even those who really want to influence cannot become convinced of the significance of their decisions. Building sector customers do not know all incompletenesses of the markets in the decision-making phase and cannot obtain and understand all the information necessary for the consideration of environmental values. So, if the additional value includes a cost, a significant uncertainty connected with the additional value may in practice prevent the customer from making a choice. There have been presented so many environmental arguments of different types on the market that customer scepticism is well grounded.

If the building sector wants to create markets that take the environmental values of buildings into account, it has to remove the barriers to decision-making stated above. A so simple and unambiguous model needs to be created for the markets so that customers do not feel uncertain when making purchase decisions. In that case it is possible to reach the development level in full customers are ready for. Still, end users' will is hardly enough to respond to those pressures directed also towards the building and real estate sectors e.g. because of international agreements. The building stock is growing fast. Green house emissions must be reduced already from the present level. If the necessary reductions of environmental impacts will be realised, in addition to the influence of the customers' purchase decisions, costs of externalities need to be directed towards those causing them or more strict regulations are needed

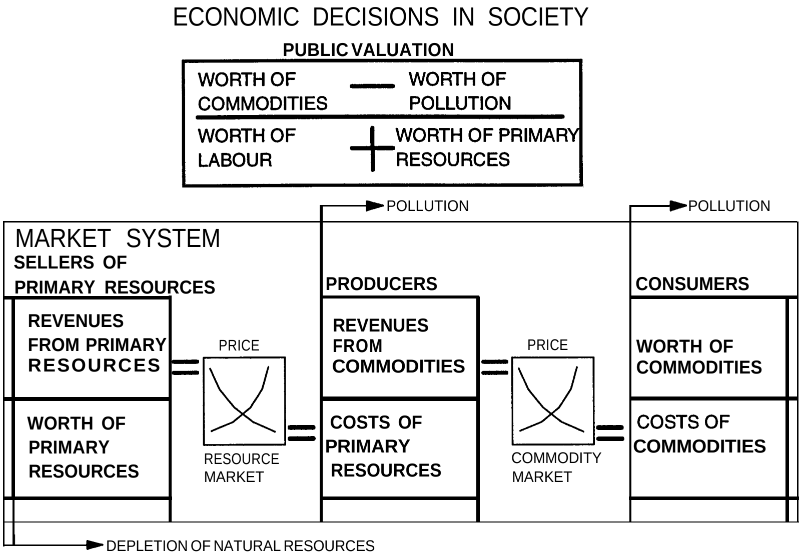

Figure 3. *Decision-making concerning exchange of commodities between economic units [11].*

2.5 Assessment of the environmental impacts of buildings

The central goals in the assessment of the environmental impacts of buildings are identification of improvement needs and comparison of development alternatives. On this basis it is possible to set operational development targets and to direct product development towards essential factors. Assessment of the environmental impacts of buildings is always a difficult and comprehensive task. The results are affected by many factors. Scoping of analyses have a significant influence. The results depend on whether average data or data from a specific production plant are used. It is also difficult to update the vast store of data required. Environmental impacts calculations of a building cannot be entirely unambiguous. Therefore buildingwise calculations do not well apply to an unambiguous verification of these issues. It is safer to verify the environmental quality of buildings by using indicators well applicable to the most important impacts.

This study has not utilised the common life cycle assessment (LCA) but the combination of the input-output analysis and LCA. In practice, the input-output table was specified and extended with information from single production processes. The input-output analysis is at its best when wide entities are being studied.

In addition to materials and work contribution necessary for the production of commodities, also machines, industrial and office spaces, means of transport as well as storage and commercial spaces and maintenance of them are needed. By utilising the input-output analysis it has been discovered that in the analysing of the environmental impacts of built spaces also the effects of capital and service inputs have influence on the environmental impacts originating in the construction industry. Energy consumption concerning several products in the building material production is quite small. In building construction, the quantities are large. Furthermore, the production includes several phases all using services, built spaces and machines. When considering for example the production of facade elements, the significance of capital formation, capital maintenance as well as leasing and commercial services makes a little more than 10 % of the energy amount used in production. In practice, precise control of these factors in the calculation is almost impossible. If the prices of used inputs include the costs of externalities, these factors will be taken automatically into account but concerning capital consumption only in the long term.

In this study, the input-output table was complemented with a quite small amount of emissions and natural resources. In future, it would be useful to add a wider amount of emissions to the model and, if needed, to allow lower detail accuracy. Then it would be possible to estimate roughly the significance of the building sector as generator of a larger number of emissions.

3 Conclusions

Environmental impacts of building construction and facility management need to be reduced. Some building sector customers want to have influence on the state of the environment with their purchase decisions. Environmentally friendly buildings can be attractive if the customers can assure themselves that their purchase decision is good. All customers in the building sector do not, however, find environmental values especially important. It is presumable that the goals to reduce emissions cannot be reached only by voluntary actions. In future it may be possible that the companies and their clients shall pay costs corresponding to the real environmental harms when using natural resources and generating emissions. In order to utilise the demand for environmental values, building construction and real estate branches have to create a simple and reliable way for the definition of environmental impacts of different buildings. Environmental impacts of production, maintenance, user activities and demolition need to be considered in development. In this way the central development targets shall be found which can used for design control of buildings. Furthermore, the enterprises in the construction and real estate sector shall in their strategic development work be prepared for the fact that the cost of causing all the most central environmental impacts will rise. Transferring the costs of externalities to those causing them also means that the non-material inputs which are usually left outside when assessing environmental impacts, are taken rightfully into consideration.

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References

1. Anttila, E. J. **(1996)** *Toimistorakennuksen teknisten järjestelmien ominaisuustaulukot*, Tampere University of Technology. Publications 178. Tampere.

2. Heljo, J., Nippala, E., Kalema, T. (1997) *Rakennusten lämmitystapavalinnat* Tampereen teknillinen korkeakoulu, Rakentamistalous 1997/5, Tampere.
3. Kaivonen, J.-A. (1997) Method for calculating ecological balances. *Construction Economics, 55 th International Conference, Proceedings*, Applied Econometrics Association, Neuchatel, pp. 7- 10.
4. Kaivonen, J.-A. (1997) Method for Calculating Ecological Balances. *Computers is the Practice of Building and Civil Engineering. Symposium report.* Worldwide ECCE Symposium, Suomen rakennusinsinöörien Liitto RIL r.y., Lahti, pp. 149 - 153
5. Kaivonen, J.-A. (1997) *Rakennusten ekotaseiden laskentamalli,* Tampereen teknillinen korkeakoulu, Rakentamistalous 1997/7, Tampere.
6. Niemi, *0.* (1987) *Input-Output Analysis of Building Construction in Finland,* Tampere University of Technology, Publications 47, Tampere.
7. Paavola, J. (1996) *Ympäristötalouden perusteet.* 2. painos. Opetushallitus. Tampereen teknillinen korkeakoulu, Helsinki.
8. Peattie, K. (1995) *Environmental Marketing Management, Meeting the Green Challenge,* Pitman Publishing, London. .
9. Perälä, A.-L., Niemi, *0.* (198 1) *Talonrakennuksen tuotantoenergia,* Tampereen teknillinen korkeakoulu, Rakentamistalous 198 1/5, Tampere.
1 O.Piirainen, H. (1996) *Tilahankkeen toimintolähtöinen tarveselvitys, Organisaation visioista, strategioista ja toiminnoista lähtevä tilatarpeen selvitysmalli,* Tampereen teknillinen korkeakoulu, Julkaisuja 190, Tampere, 134 s + liitteet.
1 1.Salokangas, R. (1993) Economic Selection. *CIB W55 International Symposium on Economic Evaluation and the Built Environment,* Lisbon.

Cultural Change in Construction: Generic Or Gendered?

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Abstract:

This paper discusses interim findings from a pilot research project, funded by ESRC for one year in 1997, which investigates the changing composition and culture of the construction industry. Emphasis was put upon the under-representation of women, and other minorities at the professional level, with particular reference to the specialisms of civil engineering, construction management and building surveying, which represent three key aspects of the construction professions, namely design, management and technology. Acceptance of minority individuals by the dominant group is seen as essential for them to progress and thus change the culture. The use of qualitative methodology is discussed in identifying key themes with a view to undertaking a more focused second stage study, after this initial stocktaking phase. An ethnographic approach is seen as essential to get beneath the surface - post-Latham Working Group 8's report on 'women and men in construction'. Latham has provided a 'script' for everyone to repeat, but, it is argued, little has changed, yet. Firstly internal subcultural factors which prove problematic for minority groups are identified. Emphasis is putting upon 'making the familiar strange' and describing the construction industry, 'as others see us'. Secondly, external regulatory, funding, organisational and cultural change agents are identified. There have been a range of educational initiatives and programmes, and attempts at 'changing the culture' of construction from a variety of perspectives in recent years. Key change agents are identified, both inside and outside the industry. These include a range of community and minority organisations, which have grown up around the construction industry (such as the Society of Black Architects). Governmental bodies which influence over the industry are also contributing to change, especially those with funding powers. For example the Millenium Programme requires a higher level of equal opportunities policy compliance in funded building schemes, both in terms of the composition of the workforce and in the design of buildings. There is clearly a need to change the culture and image of the industry.
Keywords: Access, change, culture, disability, ethnicity, ethnography, professions, women.

Cultural Change in Construction: Gendered or Generic?

1 Changing cultures

1.1 Research basis

This research builds on previous studies of women in surveying [1] and town planning [2], and seeks to investigate the more site-related end of the built environment professional spectrum, emphasising construction management, civil engineering, and building surveying; whilst considering architecture and housing for comparison. This research utilises qualitative, ethnographic methods [3], with some quantitative contextualisation (Table 1). Ethnography is a means of getting below the surface of 'words' and 'fronts'. The method is based on observing the culture of the various construction 'tribes', and seeking to understand their perception of 'reality', not least how they see 'others' who are unlike themselves. From this research a series of key ethnographic themes, that frequently manifest themselves in the course of contacts with organisations and conversations with individuals in the world of construction, have been developed upon which this paper draws [4], [5]. The second part of this paper is illustrated by comments from respondents relating to these themes (shown *'in italics'*). The research is topical because minorities, including women, ethnic minorities and the disabled are demanding both better design and accessibility in the built environment, and more opportunities to enter the construction professions themselves. These two factors are undoubtedly linked. Professional decision-making is not entirely socially-neutral but is influenced by an individual's perception of 'reality' as to how he (and its usually 'he' in the world of construction) sees the world, and imagines society to be. The need for the identification with the values of the construction subculture would seem to block out the entrance of both people and alternative ideas that are seen as 'different' or 'unsettling', but which may be more reflective of the needs and composition of wider society. 'Subculture' is taken to mean the cultural traits, beliefs, and lifestyle peculiar to the construction tribe [6]. One of the most important factors seems to be the need for a person to fit in to the subculture in order to succeed and progress.

1.2 Generic Considerations

There are demands for change within the industry from a range of mainstream and minority sources. Government initiatives such as the Foresight programme (Department of Trade and Industry) and Partners in Technology (Department of Environment); working groups including CISC [6], and Latham [7]; and a range of research projects have all highlighted the need for cultural change within construction. Reasons for change variously include 'the business case' ; increased efficency of industrial processes within the industry; health and safety considerations; greater competitiveness; recruitment crises; down-sizing; multi-tasking; greater flexibility; environmental, economic and social sustainability; improved human resource management, and the need for creating a climate of technological innovation and progress. The UK construction industry is often characterised as being conflict-ridden, fragmented yet feudal, dangerous and dirty, unattractive to young people, obsessed with professional status, and less productive than in other comparable European countries [S].

1.3 Gender Considerations

Many of the above initiatives adopt a generic approach, not 'disaggregating' the needs of different groups within the construction workforce upon the basis of gender, race, age or other social differences. But, many researchers would argue that the question of gender imbalance has to be taken on board, as a symptom of deeper problems, in an industry characterised by less than 5 % female employment, which is meant to be serving a society which is 52 % female, [9], [10], [11]. The Construction industry employs around 1.3 million people at present, a drop of half a million from the end of the 1980s. In spite of this state of decline, it still responsible for around 10% of the Gross National Product, employing 7% of the total male workforce, yet only 2 % of manual trade workers [12], and less than 6% of professionals in construction are women, the bulk of women in construction being employed in administrative, service, clerical, and personnel roles [13]. Arguably gender may be seen as a barometer by which to measure the overall wellbeing of an industry. In these days of manpower shortages, it is in the interests of the industry to attract, train, and retain more women and other minorities. The construction industry is not a separate planet, it does not exist in a technological vacuum separate from the wider society. Indeed its economic future depends upon being in tune with society's needs and demands. Thus the Latham Report, Working Group 8 [7] on women and men in construction is to be welcomed.

2 Changing attitudes

2.1 A new script?

It was found from the research that a Latham 'script' now exists which construction professionals can confidently recite on the topic of 'women' and 'equal opportunities': the topic has been 'done'. One gets the same sound bites again and again when seeking to elicit construction professionals' views on the position of women and other minorities in the industry [14]. A reading of Latham's 'proposals' as 'actions' imminently to be implemented can bolster this optimism [15]. The Latham-phenomenon has led to what ethnographers call 'reactivity' a feed-back loop has been created. Some might say the subject has been done to death, everyone is bored with hearing about gender, but few seem to understand what the implications are for the industry. But the fact that the right 'words' now exist, does not, necessarily, mean that the situation has changed, in terms of implementation, and 'actions'.

An element of 'secretiveness' within the construction culture was encountered, making it difficult to get a straight answer when seeking figures and 'facts', possibly because of fears of litigation, taxation and increased regulation, but this is particularly in respect of gender statistics. Also there is often a lack of clear written criteria in evidence on matters such as recruitment, promotion, career development, and qualification, and much of the system still seems to run on the 'he's a good *chap, I knew his father'* principle, with informal social and sporting networks playing a key role in the management of the industry, and the chances of work, at all levels. It would seem that relatively little has changed in the mainstream, but that nowadays, 'equal opportunities' has been taken on board as a separate minority topic, which is seen as *'adding costs'* rather than as contributing to overall economic growth, and as a valuable investment for people within the industry.

2.2 New practices?

The building site is still used as the great excuse as to why women cannot go into construction. In conversations the emphasis on the 'hardness' and 'dirtiness' of the work increases proportionately to respondents embarrassment about women' s exclusion. It seems it is not the physical site that is the real problem but rather the nature of social relations on site, in particular the ethos of pressure, and bullying, which many have commented upon [16]. The construction industry is not only highly gendered it is also strongly classed [4], quite feudal, and military in structure. Admittedly some aspects of professional work in construction are likely to result in somewhat flexible and discontinuous employment patterns, because the workforce fluctuates as new sites and projects are developed *'as the circus moves on'*. Also the whole industry is subject to 'boom and bust', and 'stop go' cycles within the economy as a whole, but, women appear to have greater difficulty maintaining employment mobility and continuity than male counterparts. Women in construction are increasingly likely to work in smaller firms or as self-employed professionals, many preferring off-site consultancy work, to predominantly on-site roles. The 'big boys' in the 'big firms' are only the tip of the iceberg, as the majority of all firms in construction are small, even though greater attention is often given to the large 'big name' contractors in Britain [17].

Subtle vertical divisions between different skills, and levels of responsibility in which every man knows his place, are reflected, in the 'map' of the construction industry produced by CISC for qualifications policy development purposes [7]. Women may feel there is no place for them in a world divided between 'officers and men' (cf Building, 14.10.94 pp 2 10-3). Black (especially afro-Caribbean) women professionals may feel even more out of place, particularly in sectors of the industry where colonial and 'ex-pat' attitudes prevail. Asian women may be the subject of racial stereotyping that typifies them as *'businesslike, obedient, and hardworking'*, especially the Chinese.

Relatively few women are to be found in senior posts (New Builder 24.3.95 'top posts still elude women'). However there are now more young professional women in construction (Table 1), and some large firms have positive recruitment programmes. But my attempts to track individual women down often resulted in my being informed, *'oh there was* one, *but she left'*: the *'there was* one' phenomenon proved common. Many have argued that attracting more women would lead to more humane forms of management which would result in greater productivity and less of a confrontational, conflict-ridden, ' macho pack culture' (compare Construction Manager October 1996, pp.5), resulting in more efficency and cost-effectiveness. Indeed it is often argued that *'what is good for women is good* for *the industry* as a *whole'*. But, one of the obstacles, it seems, is the unwillingness of managers and professionals to admit the need for drastic change, plus fear among manual trades workers of being seen as less than 'real men' in admitting dissatisfaction. The entrance of a greater range of types of people into the industry will bring new perspectives and objectives.

3 Agents of change

3.1 Alternative perspectives

In this section the situation will be considered from the 'other' side, in relation to external change agents which might transform the construction culture. These include ‘bottom up’ and ‘top down’ initiatives, that is, respectively, those deriving from community and minority groups, and those from governmental levels. In ‘the middle’ within the industry, the influence of both these forces needs to be translated into changes in educational and professional practice.

3 .2 Educational access

Many women, ethnic minorities and disabled people (not mutually exclusive categories) are interested in the built environment, because of concerns about community issues, especially the impractical and inappropriate nature of the design of many buildings. This concern may translate into a desire to enter the construction industry at some level in order to change the situation, particularly among mature women students who already have some idea about how the system works. Unfortunately the ‘windows of opportunity’ for training and advancement are still geared to the younger, rather than mature candidate [18] and the construction press seems obsessed with the lack of younger 16-17 year old manual workers (Construction News, 6.2.97 pp 2) especially the shortage of steel erectors, crane drivers and welders, which, in comparison are growth areas for women in the USA [19]. Generally one finds that women seem to be more concerned about the caring, environmental and design aspects of the built environment (but this does not preclude a parallel enthusiasm for technological and scientific aspects too). One does not see these interests fully reflected in the publicity material for careers in construction, or integrated within course subject-matter.

More women have been entering professionally-exempting built environment courses since the mid 1980s [1], [2], but there has been a gradual decline in recent years, especially in surveying, as if women have ‘tried’ the construction professions, not thought much of them, and moved on to other areas, especially law, accountancy, media studies, and environmental courses. Even on courses where there has been a substantial number of women and commendable completion rates, some of those who qualify may subsequently ‘vanish’ (compare the ‘*there was* one’ factor discussed earlier). Some are taking a temporary career break to rear children but others are not ‘dropping out’ but positively going into other more interesting fields. Among these are women who are still very interested in built environment and building design issues, but who channel their energies into the voluntary sector.

For young women, and men, the changeable and uncertain nature of the industry may discourage them from investigating it as a career choice. *'It's* a *rubbish industry, there 's no future in it '*. But potentially women’ s need for career breaks and maternity leave would fit in well to the industry’s project-driven employment patterns and need for flexible workforces. There are more students studying leisure, sport and recreation degrees than the total on all built environment courses, and four times the number of students on hairdressing courses than on construction courses at the technical college level. There are now small cohorts of women on most courses (7% on average, with considerable variation between courses), but this is hardly a growth area. But, initial access is now easier, because of the expansion of higher education. In comparison architecture continues to attract by far the greater number of women, and men, with 30% women being common on courses. The emphasis in architecture upon ‘design’ and ‘environment’ and ‘changing things’ and ‘working for the community’ are key incentives for women. Construction courses are struggling for students, yet much of their course material activities are not that different from architecture [20].

Many students, both male and female, become disillusioned or chose alternative career paths having entered architecture, as only 25 % of those who enrol ever become architects [21] and a similar figure applies to civil engineering. Women are likely to drop out early on, or continue doggedly to the end. One problem is the question of ‘fitting in’ to the respective subcultural image of each profession, none of which were designed with women or non-white groups in mind. Women may be confused by the multiplicity of different professional bodies and demarcations [22]. Educational initiatives such as the Construction Careers Forum are seeking to create a better, less fragmented ‘image’, so recruits are clearer as to which specialism might suit them best.

3.3 Minority organisations

A range of women, ethnic minority and disabled construction professionals, who have given up on the mainstream, are to be found in community, charity and campaigning groups. Far from altering the culture of construction, a series of new satellites are now circling ‘Planet Construction’ with their own subcultures and organisational structures. Significant groups include the Centre for Accessible Environments; Planning Aid for London; London Women and the Manual Trades; the Society of Black Architects, and Women’s Design Service.

Those actively involved are admittedly quite small in number but they may be seen as a force for change in that they form part of a powerful network of alternative groups, they are often highly productive in publication, research and campaigning. Also the organisations they run offer a model of alternative mangement structures, which are often based on a more co-operative, inclusive attitude towards employees at all levels, and a greater level of the communication with ‘society’ particularly when their ‘client’ is the community, or a disadvantaged or under-represented minority group. Whilst it may be argued these organisations are not commercial enterprises and therefore irrelevant as models for the construction industry, yet their ability to achieve a great deal with limited resources shows they have a respect for the ‘cost factor’ and for efficency, economy, and flat management structures, which might be emulated. For example, one often finds among women’s groups a complete lack of the social division between manual trades and professional levels found in the mainstream industry, with everyone seeking to integrate childcare considerations into the working day. Many women take a more holistic viewpoint towards the construction process, seeking to incorporate environmental and sustainability priorities. In contrast some young people seem perceive construction and environmentalism to be quite incompatible, particularly in respect of road building, the eco-warrior Swampy epitomising this trend.

3.4 Governmental bodies

Central government ministries responsible for industry and the environment are ‘over and above’ the industry and can be instrumental in generating change, and if necessary, enforcing it. Also some ad hoc governmental funding bodies, for example, those responsible for the Lottery, Millenium, Sports Council, and Arts Council all have higher equality opportunities requirements and accessibility design standards than are found under ‘normal’ legislation, and can insist upon higher levels of ‘contract compliance’ in new construction above current Building Regulation and employment legislation in respect of ‘what’ is built, and ‘who’ is building it [23]. Voluntary, community and minority groups are likely to be among the beneficiaries of such grants, thus enabling them to produce exemplar schemes in terms of both design and employment practice. But, black groups may still feel excluded even when other community groups are getting recognition, particularly when it comes to 'competitions' for new schemes. Many are critical of the perceived racism of some such organisations and also housing associations who put black women professionals on their management committee, 'because *it looks good'*, but never actually use black professionals or contractors in construction projects [24].

Local government bodies are also able to play a role in improving standards in the construction industry, for example by co-ordinating Local Labour in Construction Schemes, such as GLLiC in Greenwich [25], in association with major developments in the area, and in liaison with training schemes and local small business initiatives. Also, many London borough town planning departments make it a requirement of any major planning permission that certain equal opportunities measures and design features should be integrated in the development [26].

4 Future cultural change

4.1 Conclusion

The combination of pressures to change the culture from within, the activities of satellite pressure groups, and the power of governmental regulation may with time ameliorate the nature of the construction culture - and then women and other under-represented groups will enter freely, enthusiastically and in greater numbers. But, there is also fear of a backlash as some male construction professionals appear quite defensive when they realise that equal opportunities policy does not just affect women but may mean mainstream changes in <u>their</u> own lives and careers too.

Whilst it should not automatically be assumed that 'more means better' in respect of increased minority participation within the industry, it is likely that women in particular will bring a wider and innovative perspective, particularly a more 'sustainable' approach. Sustainability originally [27], incorporated three components of: - economic viability, social equality and environmental balance, but ironically in Britain, unlike Sweden, the latter has often been stressed at the expense of social equality. The way forward is to pursue all three, for the good of the industry, the economy, the whole of society . . . and the planet.

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References

1. Greed, C. (1991) *Surveying Sisters: Women in a Traditional Male Profession*, Routledge, London.
2. Greed, C. (1994) *Women and Planning: Creating Gendered Realities*, Routledge, London.
3. Hammersley, M., And Atkinson, P. (1995) *Ethnography, Principles in Practice*, Routledge, London.
4. Evetts, J. (1996) Gender *and Career in Science and Engineering*, Taylor and Francis, London.

5. Miles, M. And Huberman, M. (1996) *Qualitative Data Analysis,* Sage, London.
6. CISC (1994) Occupational Standards fur Professional, Managerial, and Technical Occupations in Planning, Cunstructiun, Property and Related Engineering Services, Construction Industry Standing Conference (CISC), The Building Centre, London.
7. CIB (1996) Tomorrow's Team: women and men in construction, Working Group 8, Latham Report, *Constructing the Team,* Construction Industry Board, London.
8. Langford, D., Hancock, M. R., Fellows, R., And Gale, A. W. (1994) *Human Resources in the Management* of *Construction,* Longmans, Harlow, London.
9. Gale, A. (1992) The construction industry's male culture must feminise if conflict is to be reduced: the role of education as gatekeeper to a male construction industry', P. Fenn And R. Gameson (eds) *Construction Conflict Management and Resolution*, Spon, London.
10. Druker, J., White, G., Hegewisch, A., And Mayne, L. (1996) Between hard and soft HRM: human resource management in the construction industry, *Construction Management and Economics,* Vol 14, pp 405-416.
11. Rhys Jones, S., Dainty, A., Neale, R., and Bagihole, B., (1996) Building on fair footings: improving equal opportunities in the construction industry for women, *Proceedings of CIB Conference,* Glasgow.
12. Wall, C. And Clarke, L. (1996) *Staying Power: Women in Direct Labour Building Teams,* London Women and the Manual Trades, London.
13. CITB (1996) *The Cunstructiun Industry: Key Labour Market Statistics,* Construction Industry Training Board (CITB), London.
14. Barnes, J. *(1997) Women's Participation in the Training Environment of the Skilled Manual Trades in the Contruction Industry,* Internal Report, UWE, Bristol.
15. Sharpe, S. (1995) Great expectations: young women today think the battles have been won, *Everywoman,* Dec 1994/Jan 1995, No 110, pp 14-16.
16. Brown, N. (1997) Bullying and Harassment in the construction industry: a cause for concern, or just part of the Job? Dissertation, University College, Chester.
17. Druker, J. And White, G. (1996) *Managing People in Cunstructiun,* Institute of Personnel and Development, London.
18. Cargill, J. (1996) Holding back the years, *Building,* 12.4.96, pp 40-41.
19. Cantrell, P. (1996) Blue collar workers: breaking through the brick ceiling, *Ms Magazine,* Vol VI, No 4, pp 34-37, Boulder, Colorado.
20. WAC (1993) *Women Architects,* Women Architects Committee, RIBA, London.
21. Kirk-Walker, *S.* (1997) *A Report of the Survey of First Year Students in Construction Industry Degrees,* Institute of Advanced Architectural Studies, York.
22. Leveson, R. (1996) Can professionals be multi-skilled?, *People Management* 29.8.97, pp36-41, Institute of Personnel and Development, London.
23. Arts Council (1996) *Equal Opportunities: Guide,* National Lottery, London.
24. Harrison, M., And Davies, J. (1995) *Constructing Equality: Housing Associations and Minority Ethnic Contractors* Joseph Rowntree Trust, London.
25. LWMT (1996) *Building Careers: Training Routes fur Women,* London Women and Manual Trades, London.
26. Booth, C (1996) Breaking down barriers, in C. Booth, J. Darke And S. Yeandle (1996) *Changing Places: Women's Lives in the City,* Paul Chapman: London.
27. SMENR (Swedish Ministry of the Environment and Natural Resources) (1994) *Rule and Representation of Women in Urban and Regional Planning,* Stockholm.

TABLE I: MEMBERSHIP OF THE CONSTRUCTION PROFESSIONS 1996										
BODY	STUDENT MEMBERS			FULL MEMBERS			TOTAL MEMBERSHIP			% of Whole Sector
	Total	Female	%	Total	Female	%	Total	Female	%	
Royal Town Planning Institute ∑	2196	957	43%	13698	3025	22%	17337	3972	23%	6% #
Royal Institution of Chartered Surveyors	8193 †	1267	15.5%	71865	4886	7%	92772	8062	8.7%	35
Institution of Structural Engineers	4358	586	13.4%	10114	137	1.3%	21636	951	4.4.%	5
Institution of Civil Engineers	8353	978	11.7%	53721	1841	3.5%	79480	3425	4.3%	26
Chartered Institute of Building	9859	620	6.2%	10244	94	0.9%	33143	903	2.7%	5
Architects and Surveyors Institute	-------	------	-------	----------	--------	-------	5046	130	2.5%	2
Royal Institution of British Architects	3500	*	31%	22670	1819	8%	32,000	*	12%	11
Association of Building Engineers	327	34	10.4%	2292	39	1.7%	4577	104	2.3%	2
Chartered Institute of Building Services Engineers	2196	116	5.28	6275	66	1.05%	15264	319	2%	3
Chartered Institute of Housing	4190	2654	63%	8258	3465	41%	13490	6375	47%	4
Architects Registration Board, ARCUK	-----	-----	-----	-----	(UK only)		25153	2892	11.5%	ARCUK
British Institute of Architectural Technology (Total membership only)	**Of 1.3 million in construction 15% are professional, of these, 6% are women: 0.9% of total**			**Approx Total for All** 195000	12000	6%	5495	182	3.3%	2

* RIBA figures are approximate owing to new format of presentation of figures on education statistics and membership. † Changes in total compared with previous figures may be account& for by revisions in body's categories etc, but check the overall proportions. In some cases intermediate, honorary and licentiate categories make up the remainders of the totals. ∑ Figures for RTPI as at end of 1996. # eg planners comprise 6% of all construction professionals

C. Greed 1997

Environmental Book of Specifications and Qualitative Assessment Method for Green Secondary Schools

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Abstract

In France, the Region of Ile-de-France now integrates an Environmental Quality approach into its projects of new secondary schools. A first green secondary school has just been built according to this approach.

The CSTB and GOIC assisted the Region Ile-de-France in designing, among other things, an environmental book of specifications, and a simplified qualitative method, both adapted to the projects of green secondary schools in Ile-de-France.

The environmental book of specifications is a document which completes the functional brief of the Building Owner. In the framework of the competitions launched by the Region, this book of specifications is part of the calls for tender.

The book of specifications is structured in 14 environmental quality targets, themselves divided in sub-targets. It comprises, for each target, a definition, environmental requirements to be respected, recommendations for guiding the designers, and information asked to the Design Team at different stages of the design process. The answers to the questions relating to the pre-design stage form the input data of the qualitative assessment method.

Consequently, candidates to the competition are made sensitive to the environment from the beginning, can integrate early in their design the requirements and take into account recommendations. Furthermore, they know the points on which their project will be assessed.

The qualitative assessment method is used at the competition stage and allows the Building Owner to assess the technical and architectural solutions of the different projects submitted, in terms of improvement of the environmental quality. In coherence with the book of specifications, the method is structured in 14 targets. The assessment is made according to expert opinion, associating objective assessment and actors' points of view. For each elementary target, an assessment scale is defined. The Building Owner may define, *a* priori, a « theoretical objective level » on these scales. The assessment is translated into elementary marks, weighted within each target. The result is presented as a profile of 14 assessments, which may be if necessary aggregated according to certain rules.

Key words : assessment method, book of specifications, competition, environmental quality targets, qualitative, secondary school.

1. Introduction

Public Building Owners presently need help from environment specialists in order to implement in a concrete way their environment protection policy.

This paper presents an upstream environmental action that CSTB and GOIC carried out for the Region of Ile-de-France.

Among the numerous actions the Regional Council of Ile-de-France has undertaken regarding sustainable development, one of them consists in integrating « Environmental Quality » into its buildings. The Regional Council has chosen the reconstruction of the Maximilien Perret technical secondary school near Paris, to implement this new approach and to make an experiment. In France, the Regions are the public building owners of secondary schools.

In 1994, the Regional Council of Ile-de-France defined a programme for the reconstruction of this school, and launched a competition between five architect-contractor consortiums.

In order to integrate environmental concerns into the project, the Regional Council needed to add an environmental book of specifications to the functional brief and to define a tool for the assessment of the proposals.

A team formed by CSTB and private consultants helped the Region of Ile-de-France in this task. The first version of this set of tools was implemented for the Maximilien Perret secondary school. What is presented hereafter is the second version of this set of tools (book of specifications : completed, assessment method : under final phase).

2. Environmental Book of Specifications

2.1. Context

The environmental book of specifications [1] takes place at the brief phase. It is a document which completes the functional brief of the Building Owner. It is *in fine* targeted to the Design Team, but before, it can help the Building Owner in fixing his environmental objectives.

In the framework of the competitions launched by the Region, this book of specifications is part of the calls for tender. It is important to have this upstream action. Particularly, the architect has to integrate correctly the approach in his sketch and pre-design project.

2.2. Objectives and general features

This book of specifications has several objectives :

- to develop awareness on environment and explain the stakes
- to be associated with or integrated into the functional brief (programme)
- to provide environmental requirements to be respected
- to guide the design phases, by recommendations
- to explain and prepare the « environmental management » of the project
- to ask the Design Team for information, in order to :
    - prepare the qualitative assessment (preliminary design, competition stage)
    - prepare the detailed design

Through this book of specifications, the Building Owner is free to express his requirements. Namely, he can select his priorities, he can reinforce the requirements in changing the reference values.

The book of specifications is structured in 14 environmental quality targets, themselves divided in sub-targets.

2.3. Presentation of the 14 environmental quality targets

The notion of « environmental quality target » is a pragmatic one, mixing on one hand requirements of environment protection and creation of a comfortable and healthy medium for users, and on the other hand families of action means belonging to the building sector.

Four families of targets have been defined :

- Eco-construction
- Eco-management
- Comfort
- Health

The table 1 details the structure of EQ targets and sub-targets.

ECO - CONSTRUCTION
1. Relation of the buildings with their immediate surroundings (Use of the opportunities offered by the neighbourhood and the site / Management of the advantages and drawbacks of the plot of land / Organisation of the plot for creating a pleasant quality of life / Reduction of the risks of nuisances between the building, its neighbourhood and its site)
2. Choice of construction products and processes (Adaptability and durability of buildings / Choice of construction processes / Choice of construction products)
3. Green building site (Reduction, sorting and management of the construction wastes / Reduction of the noise on the building site / Reduction of the pollution on the plot and the neighbourhood / Management of the other nuisances of the building site)
ECO – MANAGEMENT
4. Energy management (Reinforced reduction of energy needs / Reinforced use of environmentally-friendly energies / Reinforced efficiency of energy equipment / Use of low-emission generators when combustion boilers are used)
5. Water management (Management of potable water / Use of non potable water / Certainty of the sewerage of used water / Aid to the management of rain water)
6. Activity waste management (Design of activity waste collection premises adapted to present and probable collecting systems / Sorting and management of activity wastes, adapted to the present collecting system)
7. Maintenance (Optimisation of maintenance needs / Implementation of efficient processes of technical management and maintenance / Reduction of environmental effects due to maintenance processes)
COMFORT
8. Hygro-thermal comfort (Permanence of hygrothermal comfort conditions / Homogeneity of hygrothermal ambiences / Hygrothermal zoning)
9. Acoustic comfort (Acoustic correction / Acoustic insulation / Low-transmission of impact and equipment noise / Acoustic zoning)
10. Visual comfort (Satisfying visual relationship with outdoor spaces / Optimal daylighting in terms of visual comfort and energy expenses / Satisfying artificial lighting and in complement of daylighting)
11. Olfactory comfort (Reduction of unpleasant odour sources / Ventilation allowing the exhaust of unpleasant odours)

HEALTH
12. Sanitary conditions (Creation of non-air features of satisfying indoor ambiences / Creation of hygienic conditions / Easiness of cleaning and evacuation of activity wastes / Easiness of health cares / Creation of convenience for disable people)
13. Indoor air quality (Management of pollution risks by construction products / Management of pollution risks by equipment / Management of pollution risks by maintenance or improvement / Management of pollution risks by radon / Management of risk of polluted fresh air / Ventilation for indoor air quality)
14. Water quality (Protection of collective distribution network of potable water / Keeping of potable water quality in buildings / Possible improvement of potable water quality / Possible treatment of non potable water used / Management of the risks linked to non potable water networks)

Table 1 : list of environmental quality targets and sub-targets

This list of EQ targets has been used in several green building projects in France, and has been recently discussed in the framework of an association gathering the main French actors involved in environmental quality of buildings [2].

2.4. Structure for each environmental quality target

An environmental quality target is in fact a set of elementary targets. At a whole, there are more than 50 elementary targets, called sub-targets.

Each EQ target is divided in four parts : the first one gives the definition of the target, the second one lists the requirements to be respected by the Design Team, the third one presents some useful recommendations in order to improve the result, the last one details the questions asked to the Design Team. These questions concern different points of view : architectural, technical, economical, and linked to environmental management. Furthermore, these questions are adapted to different stages in the design and planning phases : pre-design (competition), detailed project, final contracts, and construction.

2.5. Advantages

Consequently, candidates to the competition are made sensitive to the environment from the beginning, can integrate early in their design the requirements and take into account recommendations. Furthermore, they know the points on which their project will be assessed.

3. Qualitative assessment method

The qualitative assessment method is used at the competition stage in order to allow the building owner to assess the technical and architectural solutions of the different projects submitted, in terms of improvement of the environmental quality.

The assessment is made according to expert opinion, associating objective assessment and actors' points of view.

3.1. Methodology

3.1.1. Inputs

The answers to the questions relating to the pre-design stage form the input data of the qualitative assessment method. There are 27 questions to be answered at the competition stage, certain of them gathering two sub-targets at a time.

3.1.2. Organization

In coherence with the book of specifications, the method is structured in 14 targets.

3.1.3. Main steps of the method, for each sub-target

For each sub-target, an assessment scale is defined, between 0% and 100%. The method in itself proposes a description of what is level 0 and what is level 100, and also defines the intermediate levels of performance (25%; SO%, 75%). So we get a 5-level assessment scale.

In the method are defined the weightings within the set of sub-targets, allowing to pass from the sub-target assessment to the target assessment.

The method also proposes, but it must be validated or modified by the Building Owner, an “objective level” for each sub-target. It is the performance expected by the Building Owner for this sub-target. So we obtain a set of Building Owner “benchmarks”.

The assessment is divided in two parts, reflecting an environmental assessment and a valuation according to more general quality criteria.

The first part of the assessment consists in giving, by expert opinion, and most of time qualitatively, a mark (from 0 to 100%) for the proposed solution with respect to the sub-target, on the basis of the answer given by the Design Team for this sub-target. This rating is completed by a comment, justifying the assessment.

The other part of the assessment consists in giving, always by expert opinion and qualitatively, warnings or credits on other quality criteria. These other criteria are the following : “Technical”, “Human”, “Ecological”, “Investment Cost”, and “Running Cost”. The valuation scale is : + +, +, 0, -, - -, according as the proposed solution has a positive or negative influence on the considered criterion. In the case the expert has not information enough to valuate, the result is “?”. Here, there is also a comment to be added for interpretation.

The figure 1 shows the two parts of the assessment for one given sub-target.

3.1.4. Towards an environmental profile

After rating the different sub-targets, a process of weighting and aggregation allows to get one rating by EQ target.

The result is presented as a profile of 14 assessments, pinpointing both the performance of one project for each target, and the Building Owner “benchmarks”. It is possible to build comparative graphs for the different projects in competition.

If necessary, but it is only optional, the environmental profile may be aggregated according to certain rules. It could be the case if the Building Owner wants to arrange the different projects in competition, according to actors’ viewpoints. But if the Building Owner wants to communicate about the projects, it is important he keeps all the substance of the detailed results. These phases are shown on figure 2.

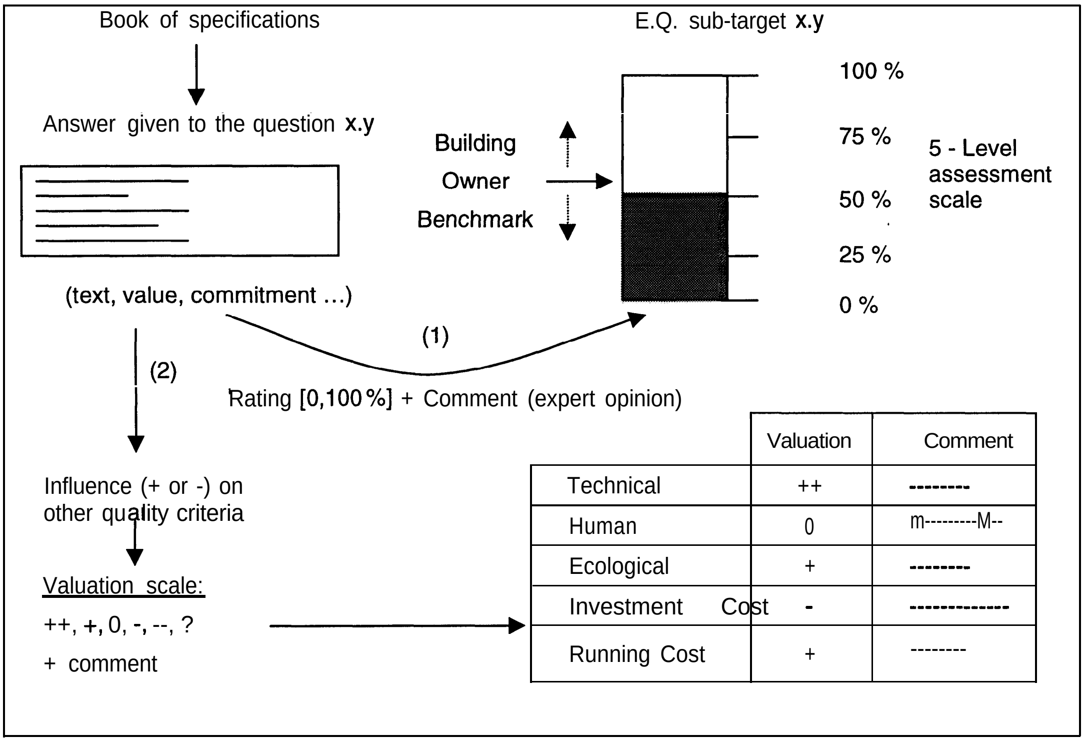

Figure 1 – Principle of the assessment method for one sub-target

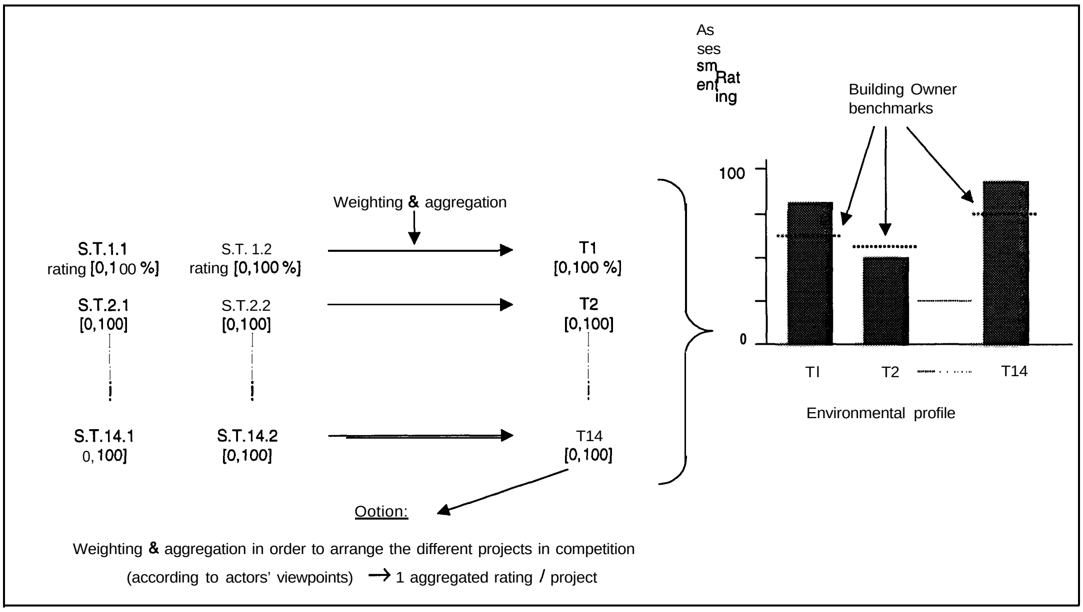

Figure 2 – Rating the environmental quality targets

3.1.5. Aggregation of results on the other quality criteria

The results of the valuation according to the other quality criteria are presented in a table crossing the criteria and the sub-targets. Then, there is an aggregation process which avoids compensation between the (+) and the (-). To each valuation is associated a weight, positive, negative or zero. A sum is performed, leading to 5 double-valuation by project, one by criteria. It is possible to aggregate more, but it is not recommended. Anyway, the aggregated results must not hide the detailed results. Figure 3 shows the way of presenting and aggregating the results on the general quality criteria.

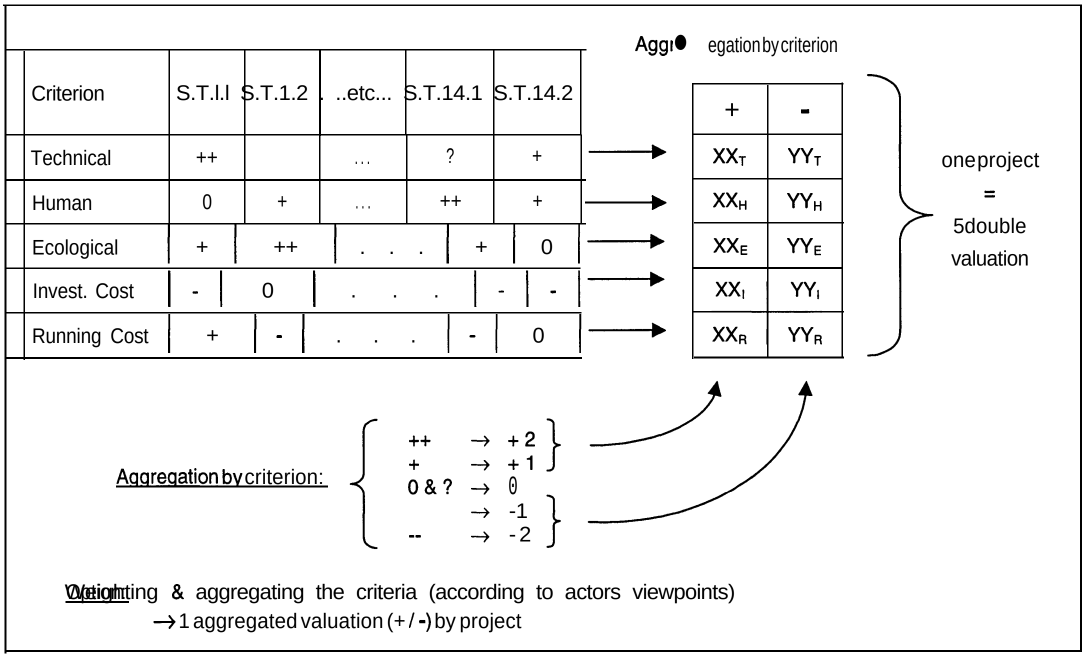

Figure 3 – Aggregating the valuation according to the other quality criteria

3.2. Results and discussion

As a summary, the qualitative assessment method leads to the following results :

- one mark by EQ target, after weighting the sub-targets
- presentation by an environmental profile (14 values)
- aggregation of results on the other quality criteria
- comparative graphs for the different projects in competition
- option for more aggregation, for a final arrangement
- possibility to go upstream in the detailed results

Through the book of specifications, the Building Owner may promote its environmental policy in fixing benchmarks. With the assessment method, he can see in what extent the candidates reach the objectives he has fixed.

The economical aspect is probably not enough developed in the book of specifications and in the method, particularly in the questions asked to the Design Team. It is a point to be improved in the future.

The assessment may be seen as a subjective one, but in fact, given the assessment scales are clearly described, the difference between two expert assessments is small.

In most of the environmental assessment methods, it is assessed (sometimes with an illusory precision) in what extent the solutions included in the project lead to reduce environmental impacts, and that's all. In our opinion, this is not sufficient.

One original feature of our method is that it does not assess the solutions only from an environmental point of view, but also according to more general quality criteria. This is essential, because environmental quality must not be disconnected from global quality of building.

Put together, the two kinds of assessment included in the method are complementary, and form a good information basis for the choice of the winner project, and for the communication about the project. It is also a good work foundation for the following phases of the design. In particular, the information contained in the assessment allows the Design Team to improve his project on various criteria.

4. Conclusion

The described set of tools allows three axis to be connected (see figure 4) :

- the environmental brief, by the book of specifications
- the assessment of the submitted projects, by the qualitative method used at the competition stage
- the environmental management of the project [3], by the recommendations included in the book of specifications (not detailed in this paper).

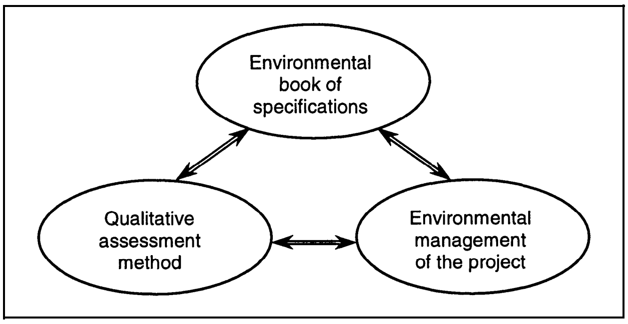

Figure 4 - Three connected elements

5. Acknowledgements

This work was funded by ARENE, which is the Regional Agency for Environment and New Energies, depending on the Ile-de-France Region.

6. References

[1] CSTB, GOIC, « Cahier des charges environnemental type pour les lycees en Ile-de-France » (Environmental book of specifications for secondary schools in Ile-de-France), Paris, July 1997.

[2] Association HQE, « Definition des cibles de la qualité environnementale des batiments » (definition of environmental quality targets for buildings), dossier n°1, November 1997

[3] Bidou D., Duchene-Marullaz Ph., Nibel S ., Olive G., « Management of the environmental quality of a building project », Second International conference « Buildings and the Environment », CIB-TG8, CSTB, Paris, June 1997.

Technologies of family house construction

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INTRODUCTION

Richness of some country can be measured via development of means of labour and technologies it utilizes. At the same time capability of new technology adoption is in accordance with standard increase. The worst obstacle to new technology development are people favouring tradition, afraid of new and reluctant to learn. Another problem is the fact that today's new technologies demand higher initial investments, developed marketing and higher mobility of labour force.The result of this is that the well-growns develop faster than those which are more in need of innovations and higher standard. This rule is valid for all economy branches including construction.

Construction, apart from food preparation, has the longest tradition in human life which necessary implies development slowness. On the other hand need for housing quality improvement requires new demands. Minimum conditions of heat and acoustic insulation, earthquake safety, energy consumption, permitted limits of different radiations and chemical influences as well as ecological conditions have already been defined in the regulations of many countries.

The above mentioned problems at development due to which less developing countries are in difficult position may be sometimes avoided.Introduction of new technologies may be considerably intensified at big projects running such as : new settlements construction or with mega projects like renewal of the complete areas after war destructions, severe earthquakes, floods etc. Croatia suffered from such tragic experience. Thus, the investigation on advantages of new technologies was started here. Partial results are presented by this paper.

PROBLEM

This is the time when materials and semiproducts with some emphasized properties ocurr i.e. when the most required criteria can be met by combination of such materials. On the other hand standard requirements, recently unpredicted climate, earthquakes, ecology etc. caused concern on approximately 3 0 different criteria while constructing family houses. These investigations present those criteria as subcriteria classified into three main criteria :

A-criterion pertaining to construction of facilities
B-criterion pertaining to expenses of facilities maintaining and use
C-criterion pertaining to housing comfort

Criterion A includes the following subcriteria in this study : Kfl-construction -- costs, Kf2 - construction time, Kf3 - mechanical equipment and Kf4 - skills. Criterion B consists of subcriterion Km1 - house damaging, Km2 -fire danger, Km3 -surface schock-resistance, Km4 - heating costs, Km5 -house maintenance costs and Km6 - house duration. Criterion C comprises the following subcriteria: Kc 1 - sound protection in the room, Kc2 - thermal radiation, Kc3 - chemical effect of the building parts, Kc4 - Influence of other radiations, Kc5 - possibility of hanging on the walls, Kc6 -possibility of wall i.e. rooms arrangement change and Kc7 - walls quality and their contact. Only a part of today’s relevant subcriteria which are used at total building evaluation was analyzed.

Subcriteria are so different that comparison can be partially carried out after determination evaluation (calculations, gantograms.. .thermal radiation.. .) and partially after evaluation i.e. stohistically. This investigation was also treated in that way.

“Method of analysis of applicable value” enables us to combine both procedures. Apart from the comparison of complete technologies, combination of some segments (the best ones) from each technology can be carried out by the same method and then compared.The above mentioned helped in analyzing i.e. comparing technologies in different phases of a family house construction.Also everything was compared with the type and technology of the facility accepted by The Ministry as an investor, for example houses without facade, final floors, paintings etc.

Conditions of construction had to be equalized at investigation of variables i.e. technologies to ensure the most reliable results. It was obtained in the way that calculation took into account as all technologies were applied for construction :

- facility of the same size occupying 57 m^2 netto of the ground floor or 1 14m^2 netto with a storey
- the same number of employees work in the same transport conditions
- purchasing prices of materials, semiproducts and the same products are equal
- facility is in III climatic zone
- equal roof loads and soil bearing power.

Comparable properties have been searched for 9 technology types. Apart from mutual comparison , all technologies were additionally compared with the type chosen by the Ministry of reconstruction. The analyzed types were as follows :

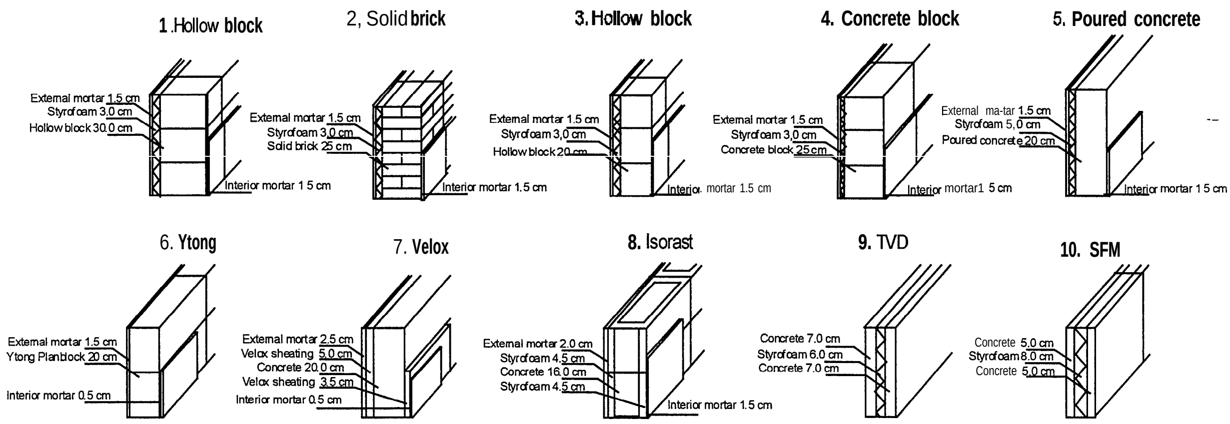

Figure 1 : Representation of the chosen technologies

Here it should be mentioned that technologies 3,4 and 5 have been mostly abandoned in Croatia whereas 1 and 2 are in fact the same ones. The only difference is that type 1 i.e. the one of the Ministry has walls of 30 cm but without vertical ties. This type has been mostly used today. Other types have only started to appear.

RESULTS OF THE INVESTIGATION

Technological innovations at family houses construction are firstly applied with walls of storey construction and overhead slabs. Stability of the house and the facility physics are the main requirements which should be met prior to any investigation. Walls per dimensions and sandwich structure can be seen from the following Table.

ordinal number	Technologies	Statistics requirements		Physics requirements		thickness of supporting wall part (cm)	thickness of thermal wall part (cm)	total wall thickness (cm)
		Minimal thickness (cm)	next standard thickness (cm)	primary material (cm)	next standard thickness (cm)			
1	2	3	4	5	6	7	8	9
1.	HOLLOW BLOCK - M	13,88	19	56,3	20	30	5,3	35,3
2.	SOLID BLOCK	14,86	25	62,8	64	25	6,3	31,3
3.	HOLLOW BLOCK	12,395	19	56,3	59	20	6,3	26,3
4.	CONCRETE BLOCK	13,67	19	53	57	25	6,3	31,3
5.	POURED CONCRETE	10	-	221		20	8,3	28,3
6.	YTONG	8,02	20	18,4	20	20	2,3	22,3
7.	VELOX	10	22	221	20	20	11,X	31,8
8.	ISORAST	10	16	221	16	16	13,1	29,1
9.	TVD	10		221		14	6	20
10.	SFM	10		221		10	8	18

Figure 2 : Table of equivalent thicknesses

Chosen walls thickness (columns 7,8 and 9) meet the needs of house statistics and physics accomplishing approximatelly equal housing conditions. Unit prices of wall m^2 of each technology were calculated by means of market standardized prices.The results can be seen from Figure 3.

Prices ($/m2)	Hollow block	Solid brick	Hollow block	Concrete block	Poured concrete	Ytong	Velox	Isorast	TVD	SFM
1	2	3	4	5	6	7	8	9	10	11
$	65.38	69.90	52.62	53.55	45.96	48.58	66.95	69.29	60.10	45.65

Figure 3 : Unit prices of wall m^2 per technologies

Prices of product units (m) neither take into account different conditions under which a building is constructed nor relation of the wall m^2 toward other building parts. Data on it can be only obtained if technologies comparison is carried out in the building construction phases. In that way dominance of some technology in different phases can be seen which is obvious from Figure 5.

Apart from the walls, the technologies are also applied at overhead slabs. Different overhead slabs were investigated relative to range change.The cheapest type of the slab was searched in various technologies. Line of the total (U) costs depending on the range change was demanded for each slab type. The line was obtained by the formula

U =F+Vxc where : F = total of the fixed costs
V = total of variable costs
C = price of m^2 of prefabricated slab

Points of intersection of minimum costs line al =a min are at the places where U1 and U2 are equal. Minimum point for the lines nl and n2 is

Unl=....

Points a2, a2, a3.....costing minimum were obtained by this procedure which can be seen from the following diagram :

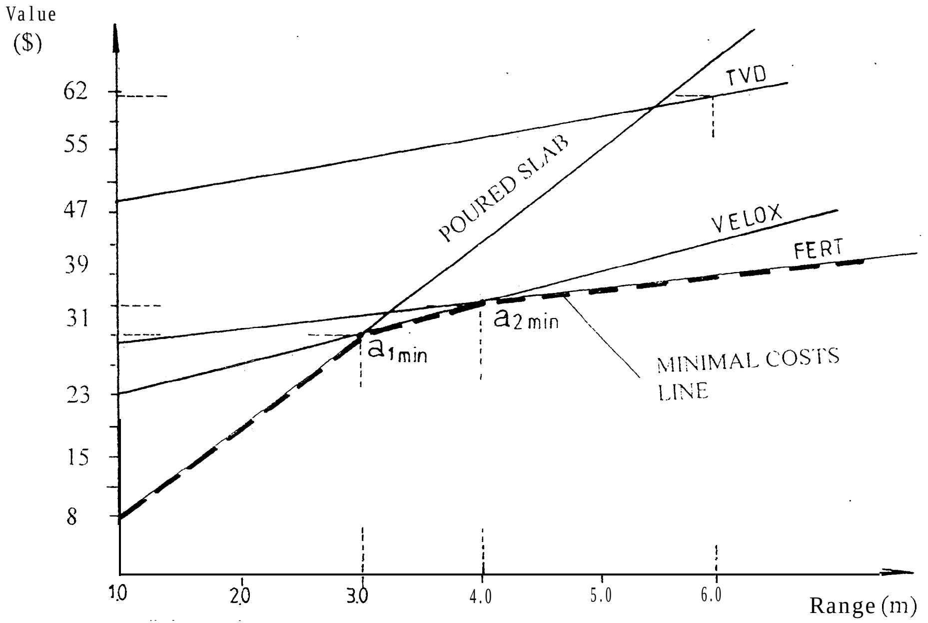

Figure 4 : Diagram of minimal costs of overhead slabs

“Fert” type of the overhead slabs is the cheapest one for ranges appearing at facility of the same type.Thus, it was mostly used for the investigation. Apart from Fert Velox and TVD slabs were also analyzed with belonging technology. Third changeable dimension is of foundations which change depending on load intensity and supporting wall dimension. Six types of foundations and three of slabs were considered at investigation of the best combination of

foundation and overhead slab with individual technology. The two most important subcriteria i.e. construction costs and duration were taken into account at choice of the most favourable combination. Once arranged buildings in each technology could be compared per various criteria and subcriteria.
Criterion A denoting favourable conditions at building construction is the most significant of the given three important criteria A,B and C. The subcriterion Kg 1" Costs of building construction" is the most important within criterion A .This subcriterion has been analyzed by calculation i.e. determination. Result for all variants (technologies) can be seen from the -- following table. The phase - finished house with facade and partial internal arrangement according to the Ministry standard (column 6) is observed in the further procedure whose determination size of coefficient Kg1 is given in column 7.

Ordinal number	Type	Storey	wall dimension (cm)	k1	total costs ($)	
1	2	3	4	5	6	7
1.	Hollow block	Ground floor	30	1,00	37092,6	1,00
2.	Solid block	Ground floor	25	0,98	37735,1	1,02
3.	Hollow block	Ground floor	20	1,05	35334,1	0,95
4.	Concrete block	Ground floor	20	1,08	34557,5	0,93
5.	Poured concrete	Ground floor	16	0,83	44339,5	1,20
6.	Ytong	Ground floor	20	1,12	32928,7	0,89
7.	(Velox	Ground floor	16	1,06	34952,6	0,94
8.	Isorast	Ground floor	20	1,10	33893,7	0,91
9.	TVD	Ground floor	14	1,09	33993,1	0,92
10.	SFM	Ground floor	10	1,20	30910,5	0,83

Figure 5 : Prices of house per construction phases

The next significant subcriterion following costs, within A criterion, is subcriterion Kf2 "Duration of a house construction". This calculation is also carried out by determination using network plans. Gantogram which can be seen in this Figure is derivative of these plans.

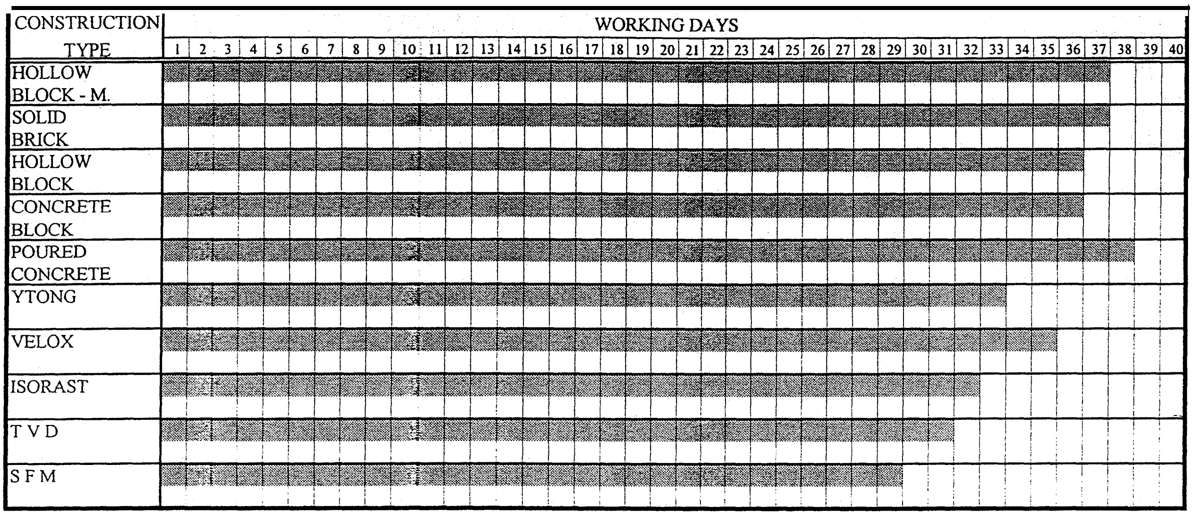

Fig.6. Total construction period

Due to limited space results of other determination calculations for subriteria Kf3 “ Mechanical equipment of a construction site” and Kf4 “Labour force skill” in criterion A as well as subcriteria Km1 “Maintenance costs”, Km2 “Heating costs”, Km3” Fire resistance” in criterion B - as well as others are not presented here.

Defined relation between technologies according to costs construction subcriterion (Kfl) was accomplished by the Table from Fig.5. Relations between technologies obtained according to construction time period criterion (Kf2) can be seen in a gantogram from Fig.6. Interrelations per technologies are obtained for all subcriteria which are investigated by determination. Since second and third criteria Ko and Ku “Housing comfort”, some subcriteria for example Ku5 “Possibility of hanging on the walls” or Ku7 “Quality and walls contact” etc. can not be measured directly thus stohastic method by dominance matrix-table is used for their comparison. Such table for subcoefficient Ku2 can be seen from Figure 7.

If variable :

V1 is larger than V2 it is marked by 1

V1 is the same as V2 it is marked by 0,5

V1 is less than V2 it is marked by 0

Criteria Kc2 : Fire resistance

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	total
V1	0	0	1	0	0	1	1	1	1	1	6
v 2	1	0	1	1	0,5	1	1	1	1	1	8,5
v 3	0	0	0	0	0	1	1	1	1	1	5
v 4	1	0	1	0	1	1	0	1	1	1	7
v 5	1	0,5	1	1	0	1	1	1	1	1	8,5
V6	0	0	0	0	0	0	0	1	1	1	3
v 7	0	0	0	0	0	1	0	1	1	1	4
V8	0	0	0	0	0	0	0	0	0	0	0
v 9	0	0	0	0	0	0	0	1	0	0,5	1,5
V10	0	0	0	0	0	0	0	1	0,5	0	1,5

Figure 7 : Table of dominance for subcoefficient Kc2

The table i.e matrix was set up by the principle of mutual comparison of variables i.e. technologies according to some subcriterion evaluating 1, 0.5 and 0. Rank position of variables i.e technologies was given on the right.
Also at criterion Km “Costs of house maintenance and use” a part of subcriterion was evalued by determination and the other one stohastically. Analysis of applicable value allows comparison of both evaluation types to be in the same dominance matrix.
Obtained position of technologies per subcriteria are a base for further evaluation.The next step is subcriteria comparison i.e. their role in total technologies evaluation. Subcriteria were firstly compared for each criterion separately in this investigation. For example criterion Km “Costs of house maintenance and use” can be used to see table-matrix of contribution for all subcriteria Km 1.. . Km6 and technologies being variants here from V1 to V1 0. Weight of each subcriterion has been defined by a weight table G. Multiplication result of the sizes in these two tables results in table-matrix of the values according to criterion Km.

Contribution	kl	k2	k3	k4	k5	k6	k7
V1	1	4	9	0	0	0	0
v 2	2	7	7	0	0	0	0
v3	4	1	5	0	0	0	0
v4	3	2	0	0	0	0	0
v5	0	3	0	0	0	0	0
V 6	7	5	4	0	0	0	0
V 7	5,5	6	8	0	0	0	0
V8	5,5	0	2	0	0	0	0
v9	8	9	1	0	0	0	0
V10	9	8	6	0	0	0	0

Veight

G1	G2	G3	G4	G5	G6	G7
1	0,7	0,5	0	0	0	0

Value matrix								total
V1	1	2,8	4,5	0	0	0	0	8,3
v2	2	4,9	3,5	0	0	0	0	10,4
V3	4	0,7	2,5	0	0	0	0	7,2
v4	3	1,4	0	0	0	0	0	4,4
v5	0	2,1	0	0	0	0	0	2,1
V6	7	3,5	2	0	0	0	0	12,5
V 7	5,5	4,2	4	0	0	0	0	13,7
V 8	5,5	0	1	0	0	0	0	6,5
V9	8	6,3	0,5	0	0	0	0	14,8
V10	9	5,6	3	0	0	0	0	17,6

Figure 8 : Table of contribution, weight and value

Order and values of technologies according to criterion Km is obtained by addition of values from matrix right side.
Tables from Figure 8 are performed for all three main criteria Kf, Km and Kc.
Finally, we are interested in the order among technologies when all three criteria are compared with all subcriteria within criteria. This can be found out if all three criteria are put into contribution matrix. Now weight of each criterion from Table G is determined in order to reach values table order.

Final technologies order is obtained in the table right from value matrix.

CONCLUSION

The main aim of this investigation was to set up such method which enables simple comparison of different technologies (or other values). At the same time adoption degrees of some technology are chosen in the phase of construction and effects testing of each technology in further building use. Such stratified choice is required since not the same technology effects are demanded in all countries.
Hundreds of different tables were used , many measurements were carried out and standards were checked during the investigation.
Original standards of building-into were set up for new technologies having no standards. Technology of "Small format prefabricated modules" has not been completely investigated, thus some data are omitted.
The investigation helped us to find out the role and technology effects in construction phases as follows: rough in a storey, more stories, storeys with foundations and roof, then only internal walls and a part of equipment in fine processing, internal walls with a part of equipment and external facade and finally complete equipment with external facade. Such precise investigation was necessary since ,due to high costs, investors prefere partly finished building and immediate use. Ministry also partially finish buildings. In that way established method of technologies comparison is tested.
On the other hand table of G weights, which can be changed, is used with subcriteria and criteria ranking. Various G sizes occur due to different understanding of priorities in some countries. We can claim that for e.g. comfort criterion in richer countries is more important than maintenance criterion which will be expressed by higher G for comfort etc.
Obtained order is the result of priorities understanding in Croatia today. The order shows that technologies with higher degree of "dry construction" i.e. semi-finished products are preferable. Thermal protection demands, for most standard technologies, facade lined by insulating layers (styrofoam, tervol, porofen, etc.) which makes facade very expensive. Technologies which solved it in a different way, TVD and SFM, are therefore more favourable.

TVD PROCESS-a high quality building process

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Abstract:
Fast and economical, TVD &Transformable Variable Design") system is a simple and performing high quality building process, which can suit any architectural shapes and standards of buildings, from social housing to luxurious habitations, with the same high quality work, especially with regards to finishing, thermal and sound insulation.

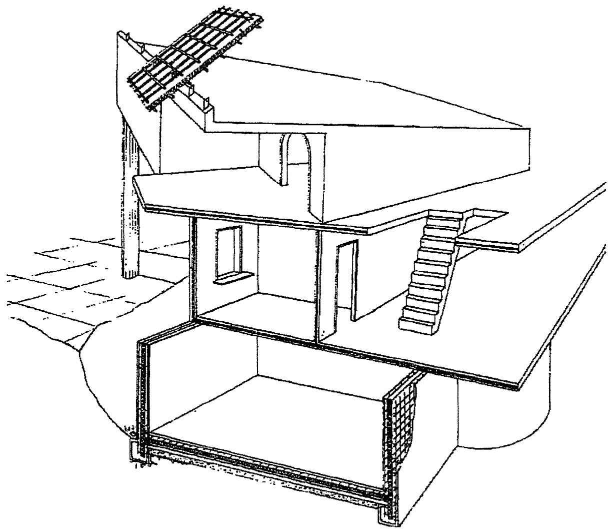


Fig. I TVD building envelope

The TVD System has been developed for any types of constructions with all the characteristics of the ones made in the traditional way. It unites planning and building in full compliance with end-user's wishes at minimal cost and in the shortest delays. The concept is simple: the available building materials are so modified that several building phases are integrated, without the use of sophisticated machines nor qualified workers.

The basis of TVD System are „Thermo- Panels", building elements that enable quick structural erection and satisfy structural, physical and ecological requirements. They consist of a prefabricated electrowelded steel frame and thermal insulation, dry-set and completed „in-situ" with a spray concrete. The panels serve as forms for vertical (flat or bent) bracing walls made out of spray concrete. Industrial production of panels, combined with the use of the typified connections and specially developed tools enable precise and quick building completion according to the project. Buildings constructed in TVD System are low energy houses, nature friendly and ecological. The TVD process as the complete building process been patented.

Keywords: TVD process, building process, technology, low cost, low cost, speed

TVD PROCESS

TVD process utilizes modern materials and methods, coupled with mechanization and rationalization of building in all its phases, from planing and design to site preparation and structural erection.

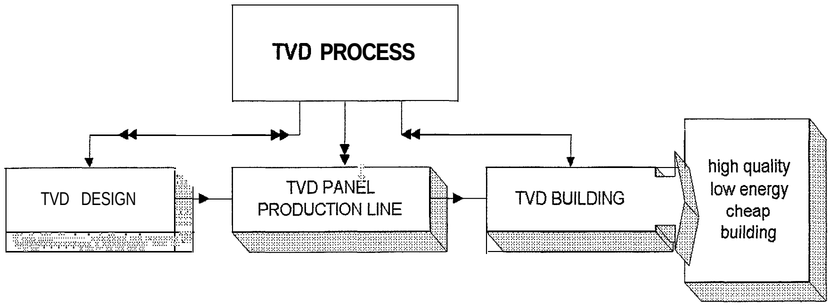
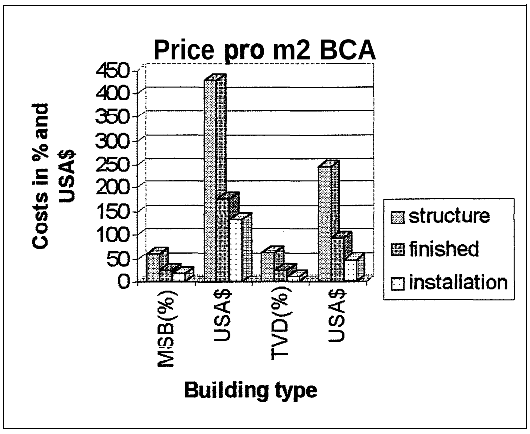


Fig. 2 An outline of the TVD process

Building costs are successively monitored from the beginning to the end, which contributes to a cost reduction and a system optimization.
This closed management system with its fully integrated specific software leads to:
* increasing productivity and progressive shortening of erection time;
* lowering non-productive work (form and shuttering works);
* suppressing heavy machines on site;
* diminishing need for qualified workers;
* enhancing high building quality with respect to its structure and finishing works;
* gaining usable area (reducing thickness of walls implies a better coefficient of brut/net area);



Maintenance
*maintenance is limited and easy;
*energy costs for heating and cooling are reduced (TVD=low energy houses);
*together with low pollution (lower CO2 emission-TVD=environment friendly houses).

Fig. 3 Comparison of the costs pro m2 for many story dwellings house

TVD design

TVD is based on modular co-ordination of measures. The basic module is 30 centimeters, the structural module is 3 or 6 meters. A great structural flexibility is assured by using various structural systems:

-wall-sandwich panels in both directions;
-wall-frame structures with openings;
-skeleton structures;
-infill elements for other structural systems (lattice work, skeleton structures, etc.).
All structural systems have a stiff slab structure for force transfer in horizontal direction.

Standardized vertical and horizontal connections of the panels are specifically &signed to enable force transfer in both directions and prevent cold bridges (direct contact between outer and inner wall sides).

These combined elements form an efficient soundproof envelope offering an excellent protection against climatic conditions, a good resistance to fire and earthquakes.

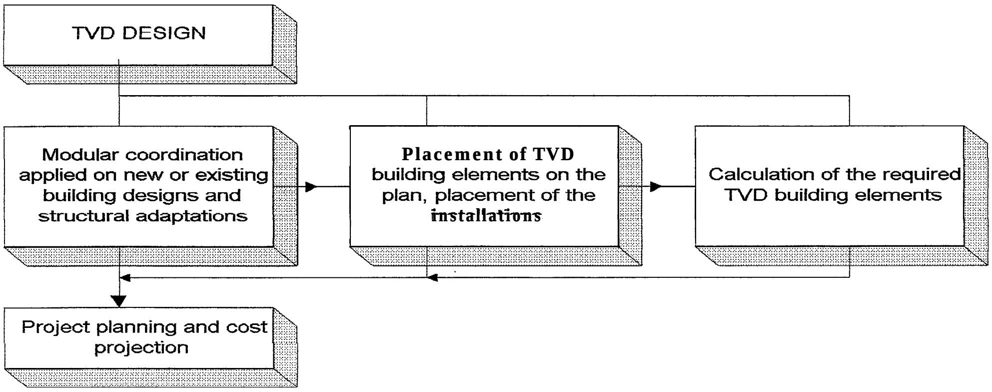


Fig. 4 An outline of the TVD design

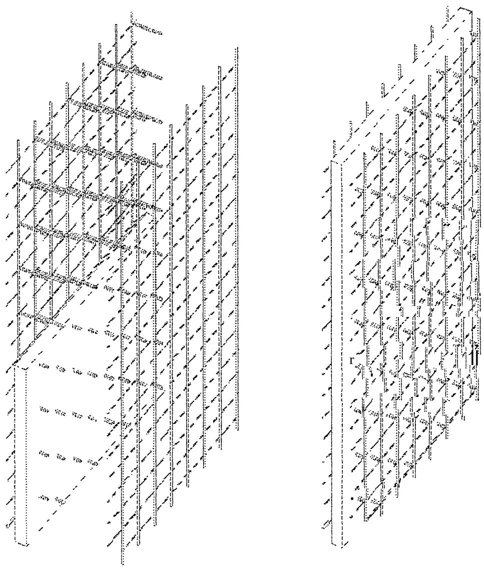
By coordinating design, flexibility of the system and freedom in the choice of finishing elements, building is fully optimized.

TVD building elements

The basic building elements are „TVD thermo- panels" which consist of prefabricated steel frame (made out of two spaced inter-connected reinforcement meshes) and the insulation in-between (which during the concrete spraying serves as a caisson), dry-set and completed „in-situ" with spraying of concrete; thus forming a purely monolithic structure with uniformed concrete walls and slabs.

Thermo-panels consist of two spaced reinforcement meshes adequately connected and enclosing insulating foam. Their construction is simple and does not require high energy consumption. The components are usually available on the market as building material.

Welded wires (reinforcement mesh) are standardized web-reinforcing wires. Panel-connections and additional reinforcement bars are made of deformed stainless steel reinforcement bars.



Connections (steel and polyethylene tiles) unite steel-mesh and thermal insulation forming a space truss system for one panel. Polyethylene disk and distance holders hold steel link bars in place and guarantee stability and distance between meshes and thermal element. Thermal element, held in place with the space truss, serves as a caisson for spraying of concrete and eliminates the need of formworks.

Thermal insulation gives its physical characteristics to the panel and stiffness it in its erection phase. This foam structure (a) stiffens the lattice and (b) serves as a horizontal or vertical support for spraying of concrete.

Fig. 5 TVD thermo-panels

Concrete is at the last stage the load bearing part of the “sandwich” panel wall and has minimal cubic strength of 25 MPa. It is sprayed on the panels in two layers.

There are different thickness of panels for the walls, slabs and base plate, each corresponding to a specific use. Panels are 0.60 to 1.20 meter wide and 2.60 to 6 meters high. The biggest building element does not weigh more than 35 kg and can easily be handled by one single person. The panels are very easy to use and any architectural shapes can be designed and further realized. The four types of panel elements serve as follows i.e.:

-bearing panels for facades and load bearing interior walls to guarantee a static, dynamic stable and resistant structure;

-non-bearing panels for partition and decorative walls;

-slab elements for floors and ceilings;

-base plate elements for foundations.

Industrial production of panels, standardized connections, adapted tools, together with a computerized control of the whole building process enable a quick and precise completion of any building, up to *8* stories high, with very little manual work.

TVD building process

1.The panels are industrially produced while the excavations are made. Their quantity and size are fixed according to the project. Once on site, the panels are directly assembled with high precision. Through unification, work is simple, repetitive and quick, including spraying of concrete. Final phases, usually done after completion of rough works (plumbing, insulating, electrical installations, plaster, rendering works, doors and windows) are already provided.

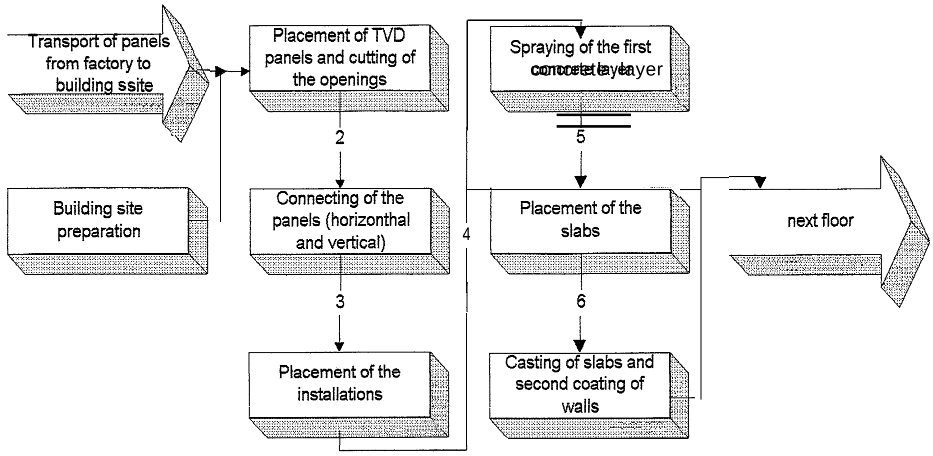


***Fig. 6 An outline of the** TVD construction process*

The use of special equipment for erection and classified connections reduces in-situ works are reduced and room for improvisation -and failure- is thereby limited.

2.**Openings** for windows and doors are precisely cut out before the erection of panels. Around the openings reinforcement is added (when needed). Special forms are placed in the openings and connected to the mesh reinforcement to keep the openings during the spraying of concrete. As an alternative, windows and doors are fixed in advance and directly connected to the meshes.

3.**Panels** are connected to the foundations with anchor bars and in-between with special links which enable unified work of panels in the wall. Additional wall reinforcement (if required by the structural analysis) and splice bars for slabs/walls connections can easily be added at this phase and connected to the mesh reinforcement. Various panel/panel and panel/slab joints (structural and non-structural) are standardized so that the whole procedure is unified and therefore simplified.
So the floor built with the panels is stable enough to serve as a caisson for the spraying of concrete. Shuttering and strutting are not necessary.

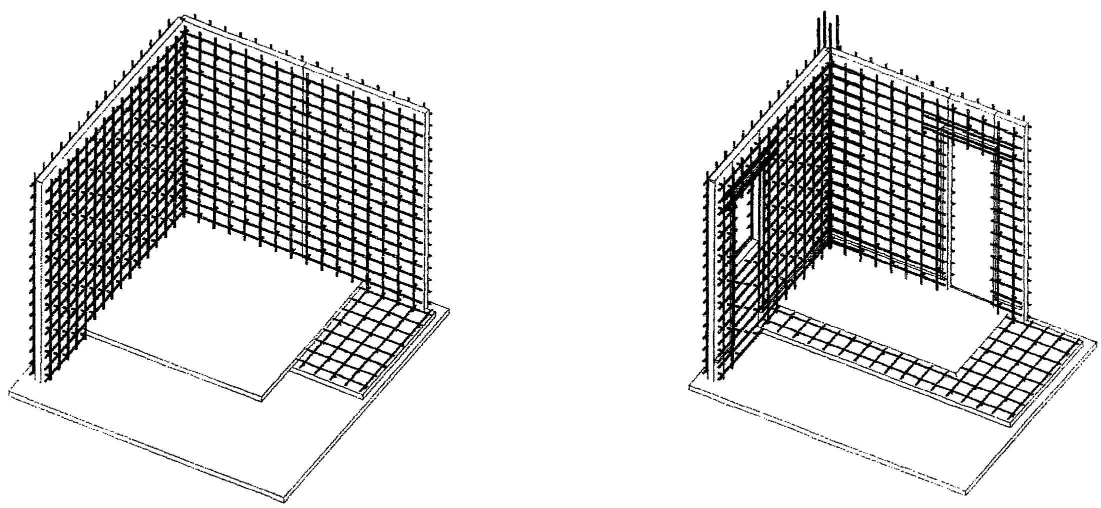


***Fig. 7** First phases **in** TVD **building** process*

4.Plumbing and electrical installations, together with related boxes, are fixed to the meshes. Insulation already exists.

5.First coating with concrete is done with aggregate mixture (0-6m.m) with rough finishing for the better adhesion of the next coating.

6.Placement of ceiling slab structure and equipment for slab finishing. Joint starter and splice bars (slab/wall and wall/wall) are added. In these phases slab strutting is needed.

7.Casting of intrados and extrados of floors and upper beams.

8.Second coating is to be carefully carried out in order to have a uniform finished surface and the required wall thickness.

For the next floor phases **2** to 8 are repeated.

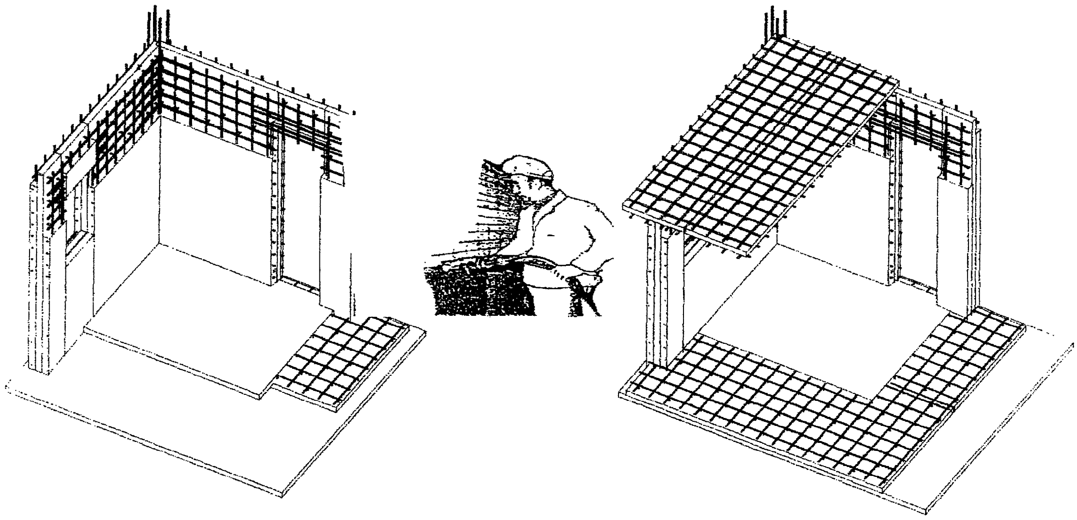


Fig. 8 Last phases of the TVD building process for one floor

Inner and outer finishing of the walls as flagging, painting and wallpapering works are the same as for traditional buildings.

References:

1. Sigmund D., Sigmund V. (1995) Thermo-panels, HPP 950572A, Croatian patent office, Zagreb

2. Orešković I., Sigmund D., Sigmund V. **(1996)** Verfahren und Bauelement zur Herstellung von Bauwerksteilen, DE 1963 6828 Al, Duetsches Patentamt, Frankfurt/Main

3. Sigmund V., Krolo J. **(1997)** Report on the static, thermal and acoustical tests of TVD panels, Building research institute of Croatia, Osijek

Sustainable Building Maintenance

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Abstract

As a part of the Sustainable Building concept, the attention for sustainable building maintenance is increasing. Unfortunately, knowledge development has focussed on new building. The available information to support and steer decisions on the existing stock from the viewpoint of durability, is therefore relatively poor.

The maintenance and refurbishment market, however, equals the new building sector in production size. This legitimates specific attention to environmental issues in this particular section of the market.

Sustainable building management is now a firm part of the Dutch governmental environmental policy. It is one of the focal points in the recent "Plans of Actions" designed by the Ministry of Housing to steer developments towards a more sustainable built environment. In recent years, several projects have been carried out, investigating the durability of maintenance activities and aiming to improve building practice.

This paper utilizes the results of these projects. It describes options for the parties involved in the building process to consider sustainability in respect to maintenance. In the design stage, the future maintenance expenditures are determined to a large extent. A well-considered selection of materials and careful detailing, helps to control the expected maintenance activities.

Principals, building owners and managers play an important role in establishing a sustainable maintenance policy, containing environmental requirements for maintenance activities. Developments towards performance contracts will affect the maintenance industry. Those contracts would then contain an agreement on the qualitative and quantitative maintenance levels to be preserved over a period of time.

Sustainability may be one of the requirements requested by the customer or even by changed building regulations. This will further increase the building team's responsibilities regarding sustainable aspects.

Keywords: Building maintenance, building process, durability, life spans, management and organisation of maintenance, sustainability

1. Introduction: the history of sustainable building

The attention for sustainable building started to grow about 20 years ago, mainly due to the increasing need to save energy. The oil crisis in the beginning of the seventies was an important turning point. From that moment onwards, governments started to be actively involved in energy saving. In a later stage, the increasing environmental awareness lead to durable building projects and legislation.

In the Dutch building regulations environmental aspects, such as the prescription of sound insulation, thermal insulation, and ventilation, and the prohibition of applying hazardous materials are covered. At this moment, more performance requirements in relation to sustainable building are added.

In the Netherlands, National Environmental Policy Plans have been made since 1989. Low energy building is widely applied. The number of refurbished dwellings with energy saving measures has increased rapidly. Research gradually supplies index numbers to compare alternative building designs on durability aspects. All parties involved in the building process are convinced of the importance of sustainable building and are prepared to support further developments. They are, for instance, entering into "Durable Building" agreements. In the housing sector, measures are incorporated in large-scale projects. In the Environmental Council for the Construction Industry parties involved in building are in continuous debate on possibilities to improve the sustainability of the building sector.

Up to a few years ago, the programmes mainly aimed at new building, and less at the existing stock or civil structures. Now, we see that urban aspects acquire more attention and building management becomes a separate object of research. Sustainable maintenance and refurbishment is gaining more awareness, specifically in the social housing sector. Many housing associations are drawing up environmental policy plans, of which maintenance and refurbishment form part. Installing double glazing, replacement of local heating systems by improved or high performance systems are normal activities for most corporations. Some of them even use listings of preferred materials.

To be able to pay attention to the sustainability of the existing stock, parties involved will need adequate information on the durability aspects of their decisions. This paper gives an overview of those aspects.

2. The maintenance and refurbishment market

In Europe the maintenance and refurbishment sector account for a building production equal to that in the new construction market. For the Netherlands, the current size of the market is over 29 billion guilders. An overview is given in figure 1 [1]. The maintenance sector increases with 1,5% per year due to an ageing building stock. The size and growth of the existing market justifies more attention for maintenance and refurbishment issues.

The building industry is responsible for a considerable share in the total waste production. For 1993, the Dutch Institute for Public Health and Environmental Protection calculated the amount of building and demolition waste to be 12,8 Mton [2]. The maintenance and refurbishment sector creates an important part of this waste, due to the small scale and labour intensiveness of the activities. Reuse and recycling possibilities are therefore important issues. This gives another reason to pay more attention to refurbishment and maintenance from an environmental point of view.

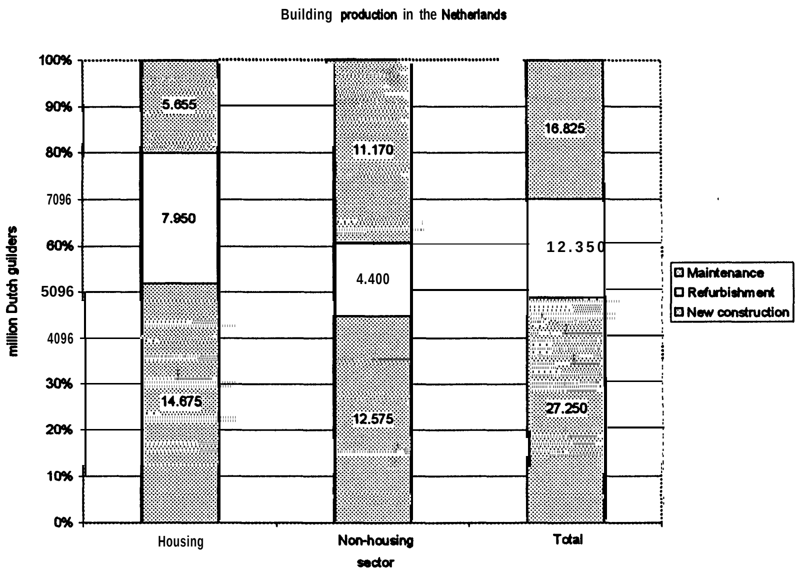

Figure 1 Buildingproduction in the Netherlands

3. Sustainable maintenance

The Dutch Environmental Policy Plans define sustainable development as "a development which fulfils the needs of the current generation without endangering the possibilities of future generations to fulfil their needs as well". Sustainable building, in line with this definition, is: building in a way that supports a sustainable development. Two types of measures can be applied to obtain a sustainable development. The first type contains measures aimed at reducing harmful effects. The second and most preferred one relates to measures for treatment at source. Those include:

- an integrated life cycle approach;
- the reduction of energy consumption;
- the improvement of the quality of products and services.

Maintenance can be described as: all "activities aiming to upkeep the performance supplied". Maintenance fits the definition of each of the sustainable measures. By extending a product's life span, maintenance reduces the demand for base materials for the production process of new components or buildings (integrated life cycle approach). Reducing the demand for a product also implies a reduction of the energy needed for production (reduction of energy consumption). And, finally, upkeeping a product's performance fits the theme "quality improvement" [3].

At the same time, however, maintenance activities themselves require material and energy. The reduction of the environmental impact, accomplished by prolonging the life span of components, should therefore be weighed against the impact imposed by the maintenance activities themselves.

3.1 Maintenance and integrated life cycle approach

The urgency to prolong a building component's life span from an environmental point of view, depends on its environmental impact during its life cycle. Data on this environmental impact are presented in so called Life Cycle Analyses. LCAs structure the environmental effects of products or activities in the different stages of their life cycle.

At this moment, no universal LCA-method exists, although several parties (for instance ISO) are working to establish such method. This obstructs the comparison of product alternatives. Therefore, a comparison presently is often based on qualitative judgements and rules of thumb. The lack of a reliable life span forecast in LCAs, vital to make a realistic estimate of the environmental impact, is another problem to be solved.

Maintenance activities have to be reviewed for their environmental implications as well, and LCAs should be developed for those activities. The impacts of a specific activity can then be compared to the impact of alternative actions. The main aspects in the evaluation of maintenance from this point of view are:

- the maintenance cycle: the more often an activity should be repeated, the larger the impact;
- the impact of the activity: for instance the amount of energy needed, pollutants released (such as dust or hazardous emissions), hazardousness of its waste (such as asbestos), and the annoyance to the building users (such as noise), indicate this impact;
- the environmental impact of the products used for maintenance (for instance solvents released in painting or glueing).

In the Netherlands, the Netherlands Steering Committee for Experiments in Housing (SEV), the Netherlands Agency for Energy and Environment (NOVEM) and the Dutch Foundation for Building Research (SBR) have published manuals with sustainable building activities for housing. These manuals also cover the refurbishment and maintenance sector [4,5,6]. Similar manuals are currently being developed for the utility sector.

3.2 Sustainable maintenance and the reduction of energy consumption

Most measures relating to energy conservation do not fit the definition of maintenance, as they imply improving the energy performance, rather than upkeeping the "old" performance. Insulation measures are, however, often applied when a component is to be replaced for technical reasons anyhow. As such, they can be incorporated in the planned maintenance policy. For instance: if a roof cover is in a bad condition, the extra costs of replacing the cover by an insulated one are relatively low, compared to adding insulation during the component's life span.

If a component is replaced before the end of its life span to install a more energy efficient component, the extra waste, material and energy use caused by this untimely replacement should be considered and weighed against the benefits of this replacement in terms of energy saving.

To reduce the energy consumption of actions, both the efficiency and effectiveness of maintenance measures should be considered. Reducing the amount of an activity is important too. The amount of building "skin" (external surface) appears to be indicative. The maintenance need of a design can be estimated beforehand, to anticipate and facilitate design revisions.

3.3 Durable maintenance and improving quality

Maintenance is only useful if a building component will remain in use for sometime afterwards. This may sound logical, but in many cases, the maintenance planning is not adapted to the owner's future plans with his building stock. The horizon of a maintenance planning can be as far as 25 years ahead. If the owner considers a major refurbishment, selling or even demolition of the building, maintenance should be adapted accordingly. Re-use and waste reduction measures should be considered.

The "repairability" of a building component is another aspect of improving quality. In relation to sustainability, there will be a strong preference for repairing components rather than replacing them. This repairability has proven to be a problem in realising a long life span for a number of so-called "low-maintenance" products. Those products indeed have a low maintenance need during the life span, but if a failure occurs by accident, this defect often can not, or only at a very high price, be repaired. A minor defect can thus result in full replacement or demolition and wastage of high quality products. Paying timely attention to repair possibilities would have prolonged the component's life span. Accessibility of components for maintenance activities should be considered in this respect as well.

Improving the quality of maintenance can also affect the choice of the activity itself. The nature of maintenance and refurbishment activities often complicates attunement between parties involved in a project. Examples of inefficient building processes are abundant. Paying more attention to the logistics of maintenance processes would favour sustainability.

4. Relationship between durability and life span

Durability in daily life is used in its meaning of "long lasting". However, from an environmental point of view, durability has many more aspects than this technical life span only; a product can only be considered durable if there is an actual need or, in market terminology: demand, for that product [7]. Nowadays, instead of the word "durable" the word "sustainable" is used.

The life span of a product should be attuned to the demand. If the demand ceases to exist, the product should either be completely disintegrated and cause as little waste as possible, or it should be re-usable (demountable and re-usable) or fit to be recycled.

For maintenance activities this implies that no maintenance activity should prolong the life span of the component longer than the required period, and that no materials should be applied lasting longer than the component's life span, unless recycling is possible. The concept of flexible, open building plays an important role in solving this problem [8].

Life span information is essential in determining the sustainability of any solution. Products with minor environmental effects, but a very short life span, can have the same environmental impact as a product with more effects but a very long life span, due to the necessary continuous replacements of the short-lived component.

At this moment, reliable life span information on buildings and their components is still missing. There is no universal, objective and internationally accepted standard method to determine the life spans of components yet, although several committees and groups, both within and outside CIB, have been addressing this problem.

5. Sustainable maintenance strategy

In recent years, the Dutch organisations SEV and NOVEM have supported projects and experiments in the area of energy reduction and sustainable refurbishment. In the DUWON-project, a methodology and manual were developed for durable maintenance in housing [5]. The manual requires housing owners to evaluate their maintenance policy from the combined viewpoint of maintenance, environment, market strategy and economics.

In the realising a more sustainable built environment, the client, whether consumer, building owner, investor or building manager has a major responsibility in requiring sustainability in the early stages of any building process, whether new building, maintenance or refurbishment.

Maintenance is a part of real estate management. As such, decisions relating to maintenance should involve more than just technical matters. Changing consumer requirements in relation to the building market as well as financial and legal matters can set preconditions and objectives for maintenance activities. These preconditions and objectives should be considered if evaluating sustainability aspects of maintenance as well. Focussing on maintenance only, may lead to suboptimisation. All phases in the building process should be considered to allow the most sustainable solution to be found.

This most sustainable solution may not always be feasible. Reasons may be the limited availability of a material or high costs or less explicit matters, such as lack of experience, implying higher application risks. Unfortunately, new products, which have not yet been tested thoroughly in practice, are often not guaranteed [9].

6. Organisation of sustainable maintenance

Sustainable maintenance involves the reduction of unnecessary maintenance. Unnecessary maintenance can be prevented by carefully planning activities on the basis of the actual building condition. Careful planning allows activities to be executed at the right moment in time, in combination with other activities, and in line with the objectives the organisation has for its real estate. This allows equipment and actions to be attuned.

In condition based maintenance, activities are based on the defects found in a building inspection. These inspections determine the performance supplied by a building. This performance will be compared to the performance required by the building owner or user. This allows actions to be exactly fitted to the requirements of a specific building. In a European research project titled “Condition Assessment and Maintenance Strategies for Buildings and Building Components”, the possibilities for implementing condition based maintenance were investigated for several European countries [10].

Duijvestein and van Hal [11] have introduced a stepwise procedure to reduce the environmental effects of building activities. The procedures review both the input and the output flow of each activity. Applied to maintenance their procedure leads to considerations as described in table 1.

Input	Output
Prevent unnecessary use Is maintenance really necessary? Can the amount be reduced? Can more efficient measures be taken, in terms of performance, life spans, environmental impact, maintenance cycle? Does maintenance solve the existing problems? How should the maintenance activity be executed to decrease the amount of future maintenance? Does maintenance have adverse consequences for surrounding components, diminishing their life spans or endangering their performance?	**Prevent waste** Is it possible to reuse existing materials? Is it possible to diminish the amount of waste due to material processing? Can the amount of packaging be reduced? Are the newly installed materials and components reusable, maintainable and repairable? Is it possible to apply used products or recycled materials? Is it possible to apply materials with a take-back-guarantee of the manufacturer?
Use infinite resources Are the materials used for maintenance renewable? Does maintenance affect the possibilities for reusing the components treated? Is it possible to use sustainable energy sources for maintenance activities requiring electricity? Is it possible to use human power in stead of machine power?	**Reuse waste** Is it possible to disassemble components in such way that they are fit for high quality reuse or recycling? Recycle waste wisely, using clean technology and ensuring possibilities for future use Can the building waste be subdivided in separate fractions? Is it possible to store the second hand goods for future use? Can activities be executed in such a way that recycling is easy in future?
Use limited resources wisely (clean technology and high return) Is it possible to execute activities in an efficient way in order to use less energy (logistics, attunement of activities)? Is it possible to use equipment, which needs less energy? Is it possible to use less material without losing quality?	

Table 1. Sustainability considerations relating to maintenance input and output

7. Performance contracts

Relatively new are the developments towards performance contracts, for instance discussed in the conference of CIB W60 in December 1996 in Tel Aviv. Next to contracts on the performance of new buildings, parties are now discussing possibilities for maintenance contracts as well.

In maintenance contracts, parties agree upon the performance level to be maintained by a supplier, usually the maintenance contractor. The customer is usually the building owner or manager. Another form, not yet applied but expected in future, is a contract between the building owner and user, expressing the performance level to be maintained by the owner and the user and the obligations and rights of each of them. Next to the technical and functional performance, such contracts could contain requirements on the sustainability of the maintenance activities as well.

8. Conclusions on future actions required

A method for evaluating the sustainability of maintenance plans should now be implemented on a large scale in the building industry and translated to fit all building types. Incorporating sustainability in the building regulations will be an important step forward and it will force building owners and' users, specifically in the private and commercial sector, to reconsider their policy.

Further research is required into the life spans of building components. Parties involved in the building process should agree on an acceptable methodology for the determination of life spans. A plan should be made to expand this methodology to obtain real life data and a forecasting model to estimate life spans of new materials and products.

Parties should also agree on a standardised LCA-method. This method should also be used to determine the environmental effects of maintenance activities. Both the effects of the activities themselves, as well as the consequences of activities for the life spans and possibilities for reuse of the components maintained, should be taken into account. By classifying activities on their environmental impact a well considered selection becomes possible. CIB could take a leading role in establishing an international task group in this area.

References

1. EIB, *The expectations for the building production and employment in 1997*, (Dutch title: De verwachtingen voor de bouwproductie en de werkgelegenheid in 1997), Economisch Instituut voor de Bouwnijverheid, Amsterdam, 1997
2. *RIVM, Data I993 - Building and Demolition Waste,* (Dutch title: Meetgegevens 1993–Bouw- en Sloopafval), 1993
3. Hermans, M.H., *Durable Maintenance,* (Dutch title: Duurzaam Onderhoud), in: Vademecum voor Architecten, part D, pp. 1 – 27, October 1996
4. Stuurgroep Experimenten Volkshuisvesting, *Manual for Sustainable Housing,* (Dutch title: Handleiding duurzame woningbouw), SEV, November, 1993
5. SEV and Novem, *Manual for Sustainable Maintenance Management in Housing,* (Dutch title: DUWON Duurzaam Woningbeheer), SEV en NOVEM, June 1997
6. Jansen, P.F.C., *National Package for Housing,* (Dutch title: Nationaal Pakket Woningbouw), Stichting Bouwresearch, Rotterdam, 1996, ISBN 90-5367-l 75-7
7. Hermans, Marleen, *Deterioration Characteristics of Building Components, A data collecting model to support performance management,* PhD-thesis, Eindhoven University of Technology, Eindhoven, 1995
8. Hermans, M.H., Quah, L.K., Damen, A.A.J., *The Market Potential of Industrialised Flexible and Demountable building for the Dutch building Industry,* (Dutch title: De marktpotentie van industrieel, flexibel en demontabel bouwen), for the Dutch Ministry of Economic Affairs, Rotterdam, 1997
9. Hermans, M., *Possibilities for extending the guaranteed life span of building products,* (Dutch title: Mogelij kheden voor een langere gegarandeerde levensduur van bouwprodukten), for the Governmental Building Agency and the Ministry of Economic Affairs, Rotterdam, 1996
10. Damen Consultants (Project co-ordinator), *Condition Assessment and Maintenance Strategies for Buildings and Building Components,* Brite Euram project 4213 for the Commission of European Communities, Rotterdam, 1996
11. Duijvestein, K., Hal, A. van, *Ecological Building,* (Dutch title: Ecologisch Bouwen), in: WEKA, Bouwen en Milieu, 2ell 1 t/m 24, WEKA uitgeverij, Amsterdam, July 1993, ISBN 90-70829-3 1-2

The South African Public Sector, Proposed Legislation and Sustainability in the Construction Industry

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Abstract
South African legislation is presently undergoing dramatic change, as the government of National Unity works to eradicate apartheid laws and introduce laws that do not discriminate Three of the proposed areas of new legislation are concerned with the built environment and development of those industries that serve it This paper offers a review of them, with particular reference to the application of sustainability, which is one of the cornerstones of government policy Providing an interesting insight into ways that sustainability can be used to develop people, and the construction industry, using it as a vehicle for the delivery of sustainable development

The paper first reviews several attempts at defining sustainable development or sustainable construction before adopting one which is used to compare the proposed legislation against

It provides details of proposed legislation intended to change the way that the government and industry interact, how the industry performs and is governed and the innovative ways that sustainability can be applied to communities

It concludes that sustainability is not defined in the proposed legislation but that it is being applied across four categories of sustainability goals Offering the idea that a precise definition is less important than a 'sustainability mindset' when formulating policy Whilst, recommending that a definition be provided for use by those who are expected to implement the policy

Key Words: Sustainability, sustainable construction, public sector, procurement reform, affirmative action, Construction industry development, socio-economic development

1 Introduction

South Africa is classified as a ‘developing’ country yet it has infrastructure that compares well with that of most ‘developed’ countries. Unlike most of its neighbouring countries, it has a world class construction industry, developed, largely as a result of the infrastructure and building programme. This development programme took place during the period of apartheid and because of the pariah status of the system foreign competitors were reluctant to participate, hence, it developed the necessary skills and expertise needed to construct modern high-rise buildings, roads, bridges and dams without their intervention. However, the ownership and management of these construction consultants and contracting firms was vested in the ‘white’ population group, whilst other racial groups were prevented from participating.

With the expulsion of apartheid in 1994 and the formation of the Government of National Unity, a great deal of emphasis was placed upon the development of people who were disadvantaged by the apartheid system. It has spurred innovation, in ways to speed the development of people who were previously disadvantaged. People development is a national priority that was encapsulated in a government priority . programme, named ‘The Reconstruction and Development Programme’ (RDP). [1]

The RDP document describes the need for socio-political development as well as economic development and the construction industry was seen to have a major role to play. Essentially, through housing, another national priority. It was envisaged that by motivating a housing programme, thousands of jobs would be created, training programs implemented, leaving local communities with homes and a set of sustainable skills.

2 Sustainability and Government policy formulation in South Africa

With the advent of the Government of National Unity in April 1 994, South Africa’s first democratic government was given a mandate to implement the Reconstruction and Development Programme. Consensus was secured among stakeholders, from across the political spectrum, on the centrality of RDP objectives to post-apartheid society. The six basic principles of the RDP are:

* An integrated and **sustainable** programme
* Link reconstruction and development
* Peace and security for all
* Nation-building
* A people driven process
* Democratisation

These broad principles are central to most of the legislation that has been promulgated since then, or that which is in the development phase. However, a full definition of the policy makers understanding of this term is lacking and we are forced to look elsewhere for this. This compares with Hoole and Milne’s [2] findings:

> *Whilst sustainable development has been widely embraced as a goal, it is still largely defined at the level of rhetoric and broad policy definition. The concept remains difficult to apply in practice.*

This appears to be true in South Africa but it would seem to be appropriate at broad policy level given Dovers assertion [3], that, sustainability could only mean something useful for policy formulation once a specific context had been identified, in terms of ‘goal’, ‘time’ and ‘space’. This should be the case when broad policy is applied to specific areas of policy implementation, such as that which concerns the construction sector.

The search for a more detailed definition in the literature shows that the concept is still being developed and further defined.

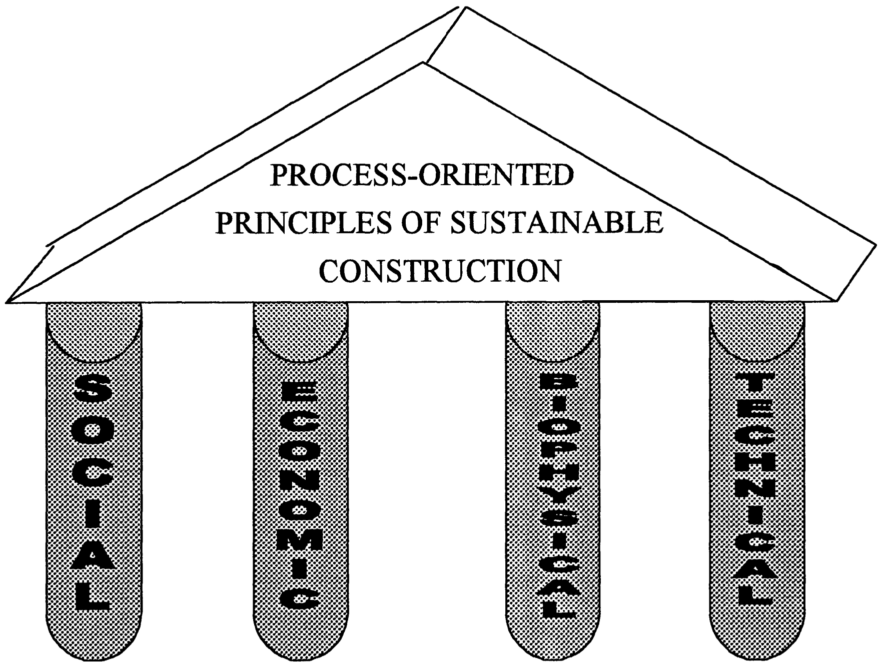

Figure 1 Principles of sustainable construction - Adapted from Hill & Bowen [6]

The World Commission on Environment and Development [4] put forward the view that the Environment and development are inseparable and intertwined. Its definition of sustainable development was, that which:

> *... meets the needs of the present generation without compromising the ability of future generations to meet their own needs.*

This early definition is now thought to be over-simplified and Barbier [5], offered a model which included three components, which together, could be described as sustainable economic development. The components being; Social system goals; Economic system goals and Biological system goals. A fourth component was added by Hill and Bowen [6], who advanced the concept of ‘sustainable construction’ whilst offering the theory that it is founded on four pillars. Supported upon which, are a number of overarching principles. The model is shown in **Fig 1**.

3 Public sector application of sustainability in construction

The Government of National Unity has embarked upon a major programme of policy development and renewal and amongst that which is still in the formulation stage are three proposals which will impact upon construction. These are:

1. Public sector procurement reform. A discussion document prepared by the procurement task team. [7]
2. Restructuring the Department of Public Works and the policies which will govern its procedures. [8]
3. Proposed legislation concerned with the creation of stability, improved delivery and value for money in construction whilst ensuring participation by previously disadvantaged persons. [9]

Each of these represents the attempts of various Government Departments, to translate the objectives of the RDP, including sustainability, into policy. In the following section, an attempt is made to show how sustainability appears to have been applied to each of them:

3.1 Public Sector Procurement Reform

This draft proposal is at the 'first draft' or 'Green Paper' stage, awaiting response from interested parties prior to being put to parliament in its next draft stage, (White Paper). The Department of Public Works (PWD) objectives are described thus:

> *The Government's aim is to transform the public procurement process in order to achieve its socio-economic objectives within the ambit of good governance.* [7]

In doing so the Green Paper recognises that the organs of state have enormous collective buying power and that public sector procurement can be used as a tool, to achieve economic ideals, including socio-economic objectives. In essence, it aims to stimulate economic growth by economically empowering, previously marginalised, sectors of society and is, clearly, more concerned with job creation and affirmative action issues than with economic of other sustainability issues. Indeed, there has been much criticism about the potential poor economic effects, in terms of the overall cost to the taxpayers who are the source of funding for infrastructure development. [10]

In order to achieve the socio-economic objectives the proposed procurement procedures must be applied in a transparent, visible and measurable manner, without compromising principles such as fairness, competition, cost efficiency and inclusion. The system is to contain the following key components:

- Removal of barriers to entry by improving access to tendering information and simplification of documents and procedures
- Breakout procurement (unbundling large projects into smaller packages) and structured joint ventures.
- Creating accelerated opportunities for target groups (weighting in favour of targeted groups)
- Small Medium and Micro Enterprise (SMME) promotion and support
- Promotion of employment-intensive practices
- Affirming marginalised sectors of society in construction projects

Many of these components have formed part of construction procurement practice, on an experimental basis since mid 1995 and, whilst there have been some problems it appears that the measures have been accepted by the industry and that the governments objectives are being achieved, at least in the short term.

In order to asses how sustainability is achieved, the following example is provided. Most of South Africa's poorest people live in rural and areas, though some urban suburbs were neglected and have similar problems. As a result, most of the present Public sector spending on infrastructure development is undertaken in these areas. In addition to the potential that the finished products offer, in terms of economic development, government policy requires that the local populace be 'developed' in the process. They are targeted and benefit in a number of ways:

- Breakout procurement will allow SMME's in the area to tender for the whole or a part of a larger project
- Joint ventures between emerging contractors and established ones are encouraged
- Contractors are required to demonstrate that they intend to employ people in the area of the project and to train them. Employment intensive practices are demanded on certain types of project, together with training.

In these ways, projects that are undertaken in rural or urban areas offer employment opportunities, training and skills development, that could be said to be sustainable. Joint ventures and other opportunities for SMME's will help them to develop skills that would improve their capacity to contract in future. Labour will earn wages that are retained in the rural community, helping it to gain momentum as an on-going economic unit. Building skills learned can be used for maintenance and construction of new buildings in that area, or in others, should the persons decide to 'follow a trade' wherever opportunities exist.

It would seem that social and economic sustainability are being addressed here.

3.2 Restructuring the Department of Public Works

In this proposal, which is at 'White Paper' stage, the Department of Public Works (PWD) describes how it proposes to change the way that it operates its portfolio of functions. It this regard it describes its aim thus: To provide and manage accommodation for line function departments; to assist other line departments in the development of policy and programmes for infrastructure delivery; and to lead the transformation of the construction industry in line with the National Public Works Programme principles. Its key functions are: property advisory services; property development; property management and the national public works programme.

It represents a dramatic change in the way that the PWD intends to operate in three functional divisions: Property investment; Property and facilities management and Project management. As it contributes to South Africa's transformation using the following strategies:

- Property investment
  - Incorporation of social objectives into property investment decisions
  - Use of investment analysis, life cycle costing and value engineering
  - Public/private partnerships in the acquisition and disposal of fixed property
  - Innovation and best practice including international benchmarking
  - Establishing a property investment policy for the entire government

  - Orientating to clients and consulting stakeholders
- Property and Facilities Management
  - Commercialisation (privatisation) of certain property services such as cleaning, security and maintenance.
  - Public/private sector partnerships whilst applying affirmative action criteria
  - Innovation and international best practice
- Project Management (the way in which it intends to manage Public Works projects)
  - Achieving socio-economic objectives through the PWD programmes
  - Influencing the construction industry
  - Improved intra-governmental relations
  - Diverse delivery models
  - International benchmarking
  - Client education
  - Adopting an appropriate organisation structure
  - Human resource development

It can be seen that the socio-economic objectives of the RDP are the basis for new this proposed policy that is to be delivered via the public works programme. All of the measures described in the procurement White Paper are applied and enhanced in this document. With regard to the property portfolio and management of those properties, it is clear that this will be used to increase private sector participation, whilst benefiting **SMME's**. Whilst much of that which is proposed is intended to replace archaic departmental practices and to 'fit-it-out' with state of the art systems and procedures that will lead to client satisfaction and good governance. With regard to existing and new buildings, structures and services, mention is made (section 5.3.1.8) of their intention to become leaders in the field of environmental management and sustainable energy utilisation.

Once again the emphasis is on social and economic sustainability with an apparent technical sustainable intentions and just an inkling of biophysical sustainability.

3.3 Proposed legislation - the creation of stability, improved delivery and value for money in construction

The title provides a clear indication of the purpose of this Green Paper, 'Creating an Enabling Environment for Reconstruction, Growth and Development in the Construction Industry'. It clearly indicates a continuation of the theme that is central to the other two but this is possibly the most far-reaching of them, in terms of its potential impact on the governance and procedures within the construction industry. The other two would affect only those firms that chose to contract with the PWD but this offers to affect all, regardless of the market chosen. Through its primary vehicle of delivery, a Construction Industry Development Board (CIDB). Its prime motivation for this and other interventions is it's assumption that the construction industry is in a crisis situation, thought to have been brought about by the impact of several deep economic recession periods. Its strategic aim is to establish an enabling environment in which the objectives of reconstruction, development and growth are realised in the construction industry.

The vision is one which *sees; a construction industry policy and strategy that promotes stability, fosters economic growth and international competitiveness, creates sustainable employment and which addresses historic imbalances as it generates new industry capacity.* It presupposes a growing and active industry, supported by an effective institutional framework representative of all parties who embrace this vision. It is premised on the ability of government to exert its influence, to foster operating practices conducive to an enabling environment. The following strategies have been proposed:

- Developing a stable environment
  - Counteracting demand volatility
  - Creation of a stable environment by addressing employment issues
- Enhancing industry performance
  - Work process transformation (partnering; Participative management; ADR; Quality and productivity improvement programmes; Health and safety; Environmental protection; Integration of design and construction)
  - Procurement practices to encourage best practice (best practice incentives; contractor accreditation; a register of contractors; monitoring of performance standards)
- Enabling strategy of human resource development
  - Establishing a new education framework
  - Towards appropriate governance of training
  - Appropriate skilling of built environment consultants
- Promoting new industry capacity and the emerging sector
  - Simplification of documentation
  - Access to improved market information
  - Access to finance
  - Payment and surety arrangements
  - Skills formation and access to training
  - Monitoring performance
- Developing the capacity and role of the public sector
  - Delivery to target the marginalised
  - Overcoming regulatory impediments to industry performance
  - Improving public sector capacity to manage delivery
- Institutional arrangements
  - A construction industry development board
  - Emerging contractor development programme
  - Monitoring and evaluation system

This piece of proposed legislation depicts a diverse array of interventions. Most of which repeat the theme set by the two draft Papers reviewed above. Clearly the primary emphasis is towards *social and economic sustainability.* However, there are also indications of *biophysical sustainability,* in terms of maximising resource usage and minimising damage to the environment, whilst *Technical sustainability* is also suggested in the pursuit of quality and other measures to improve the industries' performance.

4 Conclusions

Whilst the term 'sustainable' is used in two of the three documents no definition is provided. Each refers to the application of sustainability but it does not appear to have been applied or considered in a methodological way. It would appear to be a popular 'buzz-word' and part of the necessary jargon in South Africa at present. But there is no doubt that its component parts have been built-in to the proposed legislation that will have an effect on the construction industries.

Measured against Hill and Bowen's model of sustainable construction it would appear that there are components that could be described as fitting all four pillars of sustainability, though social and economic sustainability have received priority. Whilst there is little evidence to show that the authors of these policy documents applied a systematic approach to sustainability a number of Hill and Bowen's 'over arching principles' have been applied.

It would seem that the implementation of sustainable development policies is less dependent upon finite definitions than it is upon a culture of acceptance of its importance and a 'sustainability mindset'. However, the process could be improved, were the policy makers to adopt a model which would help those who are asked to implement the policies.

References

1. *ANC* (1994) *The Reconstruction and Development Programme,* African National Congress, Umanyano Publications, Johannesburg.
2. Hoole, A & Milne, G (1995) Defining the Features of Sustainable Development for a Developing Country: The Zimbabwe Case, *Journal of Environmental Planning and Management*, Vol 38, *No 4,* pp 505-517.
3. Dovers, S (1989) Sustainability: definitions, clarifications and contexts, *Journal of Sustainable International Development*, 2(3), pp 33-36.
4. World Commission on Environment and Development (1987) *Our Common Future,* (New York, Oxford University Press)
5. Barbier, EB (1987) The concept of sustainable economic development, *Environmental Conservation,* 14(2), pp 10 1- 110.
6. Hill, RC and Bowen, PA (1997) Sustainable construction: principles and a framework for attainment, *Construction Management and Economics,* Vol 15, pp 223-239.
7. PWD (1997a) *Green Paper* ***on Public Sector Procurement Reform in South*** *Africa*, An initiative of the Ministry of Finance and the Ministry of Public Works, Government Printer, March.
8. PWD (1998) White *Paper, Public Works Towards the 21st Century,* Department of Public Works, Government Gazette, Vo1391, No 18616, 14 January.
9. PWD (1997b) *Green Paper, Creating an Enabling Environment for Reconstruction,* Growth and Development in the Construction Industry, Co-ordinated by the Department of Public Works, Government Printer, November.
10. Kleuver, H (1996) Tender system 'obstructed', Weekend Argus, Business supplement, 17/1 8 February

Sustainable development: a challenge to the construction industry

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Abstract

Sensible environmental policies are an ethical imperative for us all, including those involved in the Construction Industry. All future industrial business (including construction) should have regard to the four 'system conditions' of the Swedish Natural Step 'Institute as a way of embracing the notion of Sustainable Development. The Construction Industry should look to lifecycle analysis as a way of addressing how sustainable its activities are in relation to Place, Process and Product. They must recognise that stakeholders (financiers and insurers; customers; employees; suppliers) will increasingly constrain its activities if they are perceived to be environmentally suspect. The Industry will need to demonstrate good (best) practice in relation to waste reduction, resource management, transport, pollution and environmental enhancement. The Industry must accept a role as advocates of Sustainable Development by developing partnerships and a Sustainable Development Code for all those in or linked to the Industry.

Introduction

This keynote lecture is to do with innovation in the way we think, the way we approach manufacturing and building processes or practices, the way we approach life itself It will begin in abstract philosophy but end in practical ideas that I hope will be of interest and help to those who both build and manage!

I will seek to address the legitimate concerns of those who suspect that the strident demands of the environmentalists are more to do with hidden political goals than with genuine concerns about global survival and hope to demonstrate that many of us who campaign on these issues do so out of a desire to secure a better quality of life for everybody and a belief that is entirely compatible with the notion of growth and development, including the physical development of land.

Environmental issues

So let me begin with the claim that a concern for environmental issues whether in the business, working or private aspects of our lives is not an optional extra. It as central as breathing or eating. Increasingly people in every walk of life and particularly in business are recognising that a carefully modelled environmental policy makes good sense economically and delivers many marketing and management benefits (and I will return to that later). There are many whose environmental urgency is born of nothing other than the fear of annihilation globally and personally and I do not wish to pretend that that is not a matter that interests us all. But there is another reason why we must take the issue seriously. There is a moral imperative also.

Without being unduly pious about it we must recognise that there are in life a range of actions that are unlawful. I do not mean illegal, but unlawful, that is against natural laws. (In the sense that Gravity is a natural law the violation of which results in something very unpleasant and probably fatal.) There are the laws of Thermodynamics (that we ignore at our peril). One of the most interesting innovations of recent years has been the campaign, known under the title The Natural Step, and developed here in Sweden.

The Natural Step

The Natural Step is an Institute offering training to businesses on changes needed to their business management, policies and practices to move to more sustainable methods.

The Institute was established in 1989 by Professor Karl-Henrik Robert who aimed to achieve consensus amongst the Swedish scientific community over the environmental problems being faced globally and nationally. From the consensus document and related discussions there emerged a definition and framework for sustainability based on resource theory. Professor Robert presented his model for sustainability and offered it as a tool for businesses to determine their priority actions for achieving sustainable business practices.

The theory is based on the laws of Thermodynamics I mentioned earlier. The first law and the principle of matter conservation is that matter and energy cannot be created or destroyed. In practice this means mining no faster than the slow geological cycles of nature and not harvesting or manipulating eco-systems in such a way that productive capacity and diversity diminish. This gives rise to the Natural Step's first and third system conditions.

According to the second law of thermo dynamics, matter and energy tend to disperse. This means that all matter introduced into society will tend to be released into natural systems and thus Natural Step advocates that persistent artificial compounds should be phased out, giving rise to their second system condition.

Natural Step's four 'system conditions' defining sustainability (all of which have profound significance for the Construction Industry) are:

- Nature cannot withstand a systematic build up of dispersed matter mined from the earth's crust.

- Nature cannot withstand a systematic build up of persistent compounds made by human beings.
- Nature cannot take a systematic deterioration of its capacity for renewal.
- Therefore if we want life to continue, we must be more efficient in our use of resources and promote their fair distribution.

The Natural Step teaches sustainable development based on these principles and the concept that this provides is agreed by all Swedish Scientists and thus can be relied upon as a secure basis for decision making for their society and, in time, others. It is a concept we should embrace in the Construction Industry as well as in manufacturing.

Sustainable development

Embracing the ideas encapsulated in The Natural Step may be the simplest way for business and industry to embrace the notion of Sustainable Development. But it is a concept that will have to be adopted by the whole of society - a process which will, in turn, exercise a profound influence on industry, including the Construction Industry. As individuals we must be concerned and as individuals in the construction business we need to be especially alert .

I have frequently heard Sustainable Development described as a phrase that is incomprehensible. I believe that is a cop-out. Perhaps the confusion, if there is confusion, is due to our putting together in an unfamiliar way two words that we normally use separately: sustainable and development. So, if we look at the words individually it might help us.

Sustainable: We use that word quite simply in the sense of something being acceptable. We might have neighbours whose teenage children have a life -style that is. When my daughters lived at home we had to have serious discussions about what sort of holidays we could afford, i.e. were sustainable! Sustainable may also be used in the same way we use the word insupportable, as in ‘that argument is insupportable’. So I think we <u>do</u> understand the word Sustainable.

Development: Coming from a background in Architecture and Planning I naturally used to think that development was only related to building. Of course it is not. It is as much about growth or change. Made as we are, we will always be pushing at the frontiers of knowledge and understanding and there is nothing wrong with that. Every time I visit the Dentist I am delighted that there has been development in the Dental Profession! We are meant to explore and progress (even at the expense of failure sometimes) to participate in the ongoing process of Creation. But we must do so in such a way as not to jeopardise all that has gone before or what may yet be possible for ourselves, our children and our world. Whilst I recognise that development means more than just urbanisation we cannot ignore how big a part physical development plays in the wider picture.

So we are talking about engaging in <u>development</u>, but in such a way that we do not harm irreparably the environment nor close down choices for future generations. Sustainable Development is not the same as Sustainability, nor is it about the return to some bygone age or rural economy. It is about being innovative in the way we use resources and skills, about creating new and better lifestyles (including better environments) for all - now and in the future. It is also, obviously, about taking care to ensure that in our management of the environment we take proper account of the impacts we are having on the natural and cultural world around us. In common parlance we must take account of the 'environmental destruction' we perpetrate. I want to challenge the common parlance, however.

Terminology

If we environmental campaigners (and I accept my place among them) are to be taken seriously we must begin to refine our terminology. Very briefly let me illustrate this:

'Environmental destruction' should describe any activity that will result in a situation that is genuinely irretrievable, no matter what money or technology is thrown at it. The cessation of all life in the North Sea as a consequence of the disposal of chemical waste would come into that sort of category.

'Environmental damage' should describe the sort of activity which may be unsightly or give rise to abnormal temporary levels of atmospheric pollution but which can be restored by the application of technology and/or money. Opencast mining might be included in that category.

'Environmental disbenefit' should describe activities that might lead to a change in the local or even national environment but which, compared to the social benefits that are enjoyed by everybody, are deemed to be acceptable. The addition of fluoride to drinking water might fall into that category.

These are the sorts of terms that should be used precisely when we analyse our actions throughout our construction and management techniques. That analysis has to be comprehensive over time and a range of activities. Again the common parlance is 'cradle to grave'.

Cradle to grave assessment

Another name for this is, of course, Life Cycle Analysis (LCA) and we must increasingly ensure that this is applied to our management systems so that it becomes as much a part of our business techniques as investment forecasting, output measurement, or staff motivation.

Properly conducted, LCA will address a wide range of issues that enable a company or organisation to demonstrate its environmental credentials under three headings, detailing what is made, how it is made and where it is made. Thus a complete LCA will provide information on Product, Process and Place. Questions will be asked about the environmental impact of the product. (In recent years the environmental downside of CFC's was exposed and in time its unsustainability led to their abandonment.) Inquiries will be made about the environmental consequences of making the product in a particular way. (An example is the amount of water or energy used in the production of paper.) Finally, and this is often not investigated with enough vigour, assessments will be required which show that a particular location where the product is made is on all counts the right one. (A company making refrigerators with inoffensive refrigerants and a process that maximises the reuse of materials and is energy-efficient but is located so close to a housing development that the noise levels from the factory create serious disturbance to the residents illustrates this kind of environmental impact).

Let me take a few minutes to address this idea of **LCA** in relation to the Construction Industry For convenience let me alter the sequence of consideration and refer to Place, Process and Product, because in the construction business location can **often** be the biggest single factor on physical development being **environmentally** acceptable.

First, then, the question of Place: Whether the construction is for housing, industrial or commercial purposes location is crucial. In the UK, and elsewhere **I** understand, there is a genuine current debate about development in the 'greenbelt' (those rural areas immediately adjacent to towns) and how much should be accommodated on 'brownfield' sites. Often lost in **this oversimplistic** argument are questions of integrating business and housing development together: housing on brownfield sites is not just about 'housing' but the range of 'social' services, like education, that can be provided.

But the 'place' issue is about much more than the urbanisation of hitherto green sites. There are questions of surface water run off from hard surfaces, the adequacy of water supply and the capacity to treat sewerage. There are other **major** questions about the energy use that the development will incur, whether in terms of transmission lines or transportation costs. Land take for access roads, the convenience of journey times, the creation of air and water pollution and access to open space are all extremely potent issues that are primarily created by location.

Next there is the question of 'how' the construction is managed, i.e. what is the 'process' involved. Among the questions that will be urgently addressed are: is the construction process water and energy efficient; are the construction materials appropriate to the locality; are they local materials or do they involve massive transportation costs? Are there just-in-time delivery systems to avoid damage and deterioration of materials stored on site? What environmental protection measures are in place during construction (e.g. noise and dust creation). **Is** the site managed efficiently to reduce pollution (including the escape of packaging materials) in the surrounding areas.

Finally, what about the 'product' (the construction itself!). Will the building be energy efficient, does it minimise water consumption by reusing s-u&ace water. What are the arrangements for good waste management, are there **composting** facilities, is good microclimate created, are there well-designed open spaces, i.e. is there real local environmental quality?

Increasingly there will be those looking for, even demanding, evidence that industry in general, including the construction industry faces up to these issues.

It should be added at this point that the same sorts of demands will be made **upon the** service sector too, whether that is the transport industry, the leisure business and the service industries producing energy, water or telecommunications. But the demand will not only or necessarily be in the form of **statutory** requirements.

Stakeholders

Companies who are already engaged in the development of sensitive environmental practices have identified at least four stakeholders whose environmental interests they have to reflect in addition to the financial interests of their shareholders (who may also, of course, have environmental interests). These are - Financiers and Insurers, Customers, Employees, Suppliers.

For the last decade or so, particularly in the USA, banks and insurers have been asking those to whom they are lending money or for whom they are providing cover, to demonstrate their environmental probity. It has largely come about as a result of them finding themselves associated with environmental offenders in legal judgements handed down by the courts. That will undoubtedly increase over there and there will be a knock-on effect here. I am told that of the claims to Lloyds of London that had such a devastating effect on the 'names', over 20 % were related to environmental disasters.

Likewise there is an increasing interest by consumers or customers in the environmental friendliness of the products they purchase and the companies which produce them Despite the disillusionment of many members of the general public about the credibility of 'green claims' put on consumer products a few years ago there remains a considerable interest in green consumerism and the work of the Eco-labelling board will stimulate this further. This is likely to produce demands for evidence that product, process and place of manufacture are sustainable. (And in a related field I suspect concern about developments in Bio-Technology will produce even more strident demands for openness and reassurance.)

The next two categories of stakeholder (employees and suppliers) are rather less predictable in that they may feel somewhat more inhibited in making their demands on business. In times of high unemployment employees are careful not to make demands that might jeopardise not only their individual jobs but cause the closure of the entire business. Similarly, materials or service suppliers are not usually so altruistic as to refuse to supply to companies whose environmental record is not good. But that will change as the general concern about environmental issues increases. There is the other side of the coin, of course, in that responsible manufacturers can bring influence to bear on their suppliers.

Single-issue groups

These four stakeholders seem to me to be entirely legitimate influencers of the corporate response to environmental concerns. There are others that seem much less legitimate. So it is perhaps appropriate at this point to address the issue of the pressure brought by single issue groups. The strength of such groups is, of course, that they are, by definition, able to focus their energies on a particular problem or even to concentrate on one side of an argument and deliberately refuse to acknowledge that there may be an alternative interpretation or judgement. In some ways that can be a very effective way of highlighting an issue and we can be grateful for it. The danger is that if those views are allowed to carry the day then any sense of balance in the environmental debate is frequently lost.

So in our careful appraisal of environmental issues and the quite proper concern to afford them their correct weight alongside other criteria we must not allow the balancing of the various arguments to be sabotaged by the blinkered concerns of single issue campaigning. Equally we dare not, for all the reasons I have outlined earlier, continue to pretend that a proper concern for environmental matters need not affect the way we conduct our business or manage our lives at the practical day-to-day level. And it is to that I now want to turn.

Practical outcome

Going for Green in the UK, which I have the privilege to chair and manage, is a public **education** campaign designed to persuade everyone to make significant changes in their lifestyles to ensure that the future is characterised by more sustainable development programmes. It is not addressed only or even primarily at business but at every individual. However, it recognises that some individuals exercise much greater influence than others so those in business and particularly in the construction business or other large institutions are a natural target. GfG's message is simple and concerns those practical day-to-day measures to which I have just referred and which, whether **applied** to personal or corporate activities will make significant changes to the way we impact the environment. So it has developed a five-point Green Code, **applicable to the** ordinary individual or to the corporate entity:

- Cut down on waste
- Reduce the use of non-renewable resources like energy from fossil fuels and water
- Travel sensibly
- Avoid pollution
- Enhance local environments

Above all it is designed to encourage people to get involved!

Waste

Badly managed, both solid waste and effluent in large quantities are bad news for the environment. In recent years increasing numbers of companies have found that a review of their waste management strategy has resulted in their being able to savagely reduce the type and tonnage of material going to landfill and use it in a combined materials recovery and recycling programme. In the UK the bottom-line benefit of this will of course be significantly increased with the advent of the Landfill Tax which as from October 1st 1995 is charged at the rate of between £2 and £7 per tonne (payable to HM Customs and Excise) on all materials that go to holes in the ground! One of the UK's retain chains, Safeway, have amassed half a million tonnes of cardboard for recycling in the last five years meaning that 100,000 refuse vehicles did **not have to visit landfill** sites - that will result in cost savings under the new Tax.

Resources

Whilst the warnings of the sixties that we would by now have run out of many vital non-renewable natural resources proved to be inaccurate and alarmist, the fact remains that these resources <u>are finite</u> and we continue to plunder then endlessly. And, of course, their availability is unevenly spread. <u>We</u> in Europe might have coal resources for 300 years: others have little or none. Already countries in the Far East, assessing their own slim hydro carbon resources are now refusing to sell them to others. We face the serious possibility of a resource war in the future. Nations have fought over other riches and this is a real threat to world peace. If you think I exaggerate ask yourself if the USA would be involved in Iraq, Iran or the Gulf States if it were energy self-sufficient itself

So on the political as well as ecological front, there is sense in being economical with what we have. Furthermore, we need to be much more sensitive about our use of renewables! Thirty years ago a lecture like this in the UK would not have said much about water. Now it is a different matter. Likewise the sensible management of forestry (both hardwoods and softwood) is imperative if we are to continue to enjoy the balanced lifestyle the planet has taken for granted up until now.

The call too has to be for less energy consumption. We must use less electricity wherever we can, if it is generated using fossil fuels and continue to press for alternative sources (wind, solar and nuclear). The use of fossil fuels for mobility too needs checking, as we will see in a moment.

Examples of the sorts of savings people have made are very impressive. **For** example, Alida Recycling Ltd., part of British Polythene Industries **PLC** has developed the technology to produce polythene bags from post-use polythene waste. The bags produced from <u>virgin</u> material require three times as much energy, generate over twice as much carbon dioxide, use eight times as much water, produce three times as much sulphur dioxide and give off double the volume of nitrous oxide.. . . and use **1.8 tonnes of** oil ! The challenge is to do more. Perhaps the Construction Industry can be the trigger for further work in this area.

Of course, for some companies, it means rethinking their very existence. The challenge of Sustainable Development is very different for the Construction Industry than it is for a petroleum company, where the very business **itself (not the way it is** done) may be perceived as unsustainable.

Travelling sensibly

In many first world countries the profligate use of resources over the last **20** years in the development of a heavily subsidised road based transportation system has to be regretted. A more balanced, integrated system for the future is essential, even if the capital investment needed is terrifying. Now let us be clear about one thing. Rail., even if it were sensibly developed cannot deal with <u>all</u> the goods and people needing (or thinking they need) to be moved about. But a more intelligent location of transport distribution centres, a different settlement pattern and constraints on the mobility of goods and labour would have dramatic environmental benefits in a number of fairly obvious ways:-

- the reduction of resource depletion
- the reduction in land take for roads
- the reduction in pollution from conventional engines

Vehicles stocked with wooden pallets carry **40%** more product than similar vehicles using roll cages. An audience like this probably needs no introduction to the merits of 'just-in-time' management, with the reduction in empty-running vehicles, waste and warehousing. A major UK retailer estimates that as many as 135,000 vehicle movements were saved in a single year. But this not just for big business. In Northern England the Aire and Calder waste minimisation scheme in West Yorkshire (1992-1995) involved 11 Small and Medium sized businesses undertaking reduction of waste and emissions in their production processes and within a year 75% had seen a reduction in operating costs.

Interestingly, health concerns deriving from the pollution is likely to produce support for unpopular measures like a Carbon Tax and the progressive development of efficient environmentally friendly engines. But the other two concerns need addressing also. We should be looking for the introduction of policies throughout the world that would constrain out-of-town shopping centres and encourage more sensible rural development.

There is no future in pretending that people will settle for the total denial of the personal mobility we have all come to enjoy. But we will have to settle for it being in differently fuelled vehicles and on networks that allow everyone some movement. Electric and gas powered vehicles are beginning to appear and 'smart card' technology that will manage traffic are already being used in some parts of the world. Total mobility for all is a myth as those who live and work in Los Angeles have known for two generations.

Avoiding pollution

I have already mentioned the idea of a Carbon Tax. Governments will be reluctant to introduce it, but the general public will in the years that lie ahead, tolerate less and less pollution from all sources. According to Dutch and USA studies between 2-10,000 people could be dying early in Britain every year as a result of particulate pollution. The 'polluter pays' principle is here to stay - even if we all know that the cost will be passed on to the end consumer. But the incentive to develop cleaner technologies that produce savings and give a competitive edge will provide an incentive to those in the business world. Cheap raw materials and labour will not, in future be the only keys to the production of goods at customer-winning prices.

Many companies are now producing very impressive figures showing a serious commitment to pollution reduction. For example Norsk Hydro UK in its latest report shows discharges of Nitrous Oxide and Carbon Dioxide down by fifth and a third respectively and it has eliminated Sulphur Dioxide discharges altogether.

IBM has this progress to report:

- At year end 1995 IBM's US 33/50 chemical releases and transfers were reduced 84% from 1988 levels, exceeding US EPA goal.
- Hazardous waste generation was reduced 71% world-wide from 1987-1995. Of the waste generated in 1995, 84% was recycled.
- Worldwide plants, laboratories and administrative facilities recycled 65% of non-hazardous waste in 1995.
- Energy conservation efforts saved $15.1 million (approximately £10 million), 226 million kWhr in electricity and 2.15 million gallons of fuel oil in 1995.

What the Chemical and Computer Industries can do should be echoed in the Construction Industry.

Environmental enhancement

It is important to emphasise that Sustainable Development is not just about prevention or reduction, about the need to do less harmful things. It is also about the positive. Many companies have made heavy capital investments to ensure that the surroundings of their buildings are as attractive as possible. You cannot sell even quality goods out of a dirty shop window. There really is no excuse for business premises, whatever the product or the service, to be anything other than elegant. In the Construction Industry which can do so much to ensure high quality environments, providing 'delight' as an outcome of the construction process should be a cardinal element in corporate programmes.

Going for Green

I have already mentioned GfG and outlined its Green Code. It is being tested in pilot sustainable communities in six local authorities, one business and I hope to see another in a major educational institution shortly. To help measure performance we have developed a single unit of measurement so that different environmentally-friendly activities can be measured against each other. The calibration is difficult but we have got there. For the moment it is called an 'eco-calorie'.

What GfG will do, if it succeeds, is change the pattern of consumer values and spending and alter public perceptions about what is desirable and possible. Those alive to the growth of a powerful voice in civil society (quite different from the single issue voices of the past) will soon recognise the necessity to be innovative in product process and place! But help is available in many different ways. Let me cite just one example in the UK - if only because my own university is involved.

The business ecology unit and other services

The four Universities here in Manchester have combined together to respond to the call from the Co-op Bank to provide an environmental service to its customers and anyone else for that matter. I can tell you getting four universities to work together is really innovative! Increasingly the new-style Chambers of Commerce and Tecs are looking to assist businesses who are seeking guidance about good environmental practice. It is all very encouraging. But it needs a major shift in the thinking of many more people, yet.

Conclusion

I am delighted to have had this opportunity to share with you something of what is happening innovatively in the field of good environmental management. But even more pleased to be able to encourage you to consider what, or what more, you can do.

I believe there is a special role for the Construction Industry. It is ambassadorial! You can help to bring about this revolution in thinking; securing a commitment to Sustainable Development. First you can do it when your clients who should have the environmental and social consequences of their buildings spelt out to them. Secondly, you can be tough on materials suppliers, making it clear that you will not consider them if they cannot demonstrate the environmental probity of their materials and thirdly, you can do much to ensure that the end users of your buildings (who may not be the commissioning clients) understand what qualities they should be demanding. In this latter case it will be necessary to develop a partnership with realtors, building federations and the like so that certificates can be issued which provide guarantees on many of these issues. (In the UK we shall be exploring the development of the Eco Cal for housebuilders). There is a genuine need for a Construction Industry 'Green' partnership to develop a Sustainable Development Code for the industry.

The great Liverpool football club manager, Bill Shankly, was once asked if something to do with the club was a life or death issue. His response: 'it's more important than that!' Well, the proper management of the environment is a life and death issue but, more importantly, is a moral issue. How we handle it is a real reflection of our humanity and says all there is to say about where we think we've come from and why we fare here. It is a challenge to the Construction Industry no less than to the rest of us!

The Energy Barometer - A new system for monitoring energy use in the housing stock.

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Abstract

A new system for monitoring energy use in the housing stock is presented. With this system, which we call the Energy Barometer, statistics on building energy use can be obtained and analyzed at short time intervals. The principal objectives of the Energy Barometer are (i) to determine levels and (ii) to detect changes of trends in energy use for heating in the single-family housing stock.

In the paper we describe how new measurement technology, Internet-based communication techniques and computer intensive statistical methods are combined into a system to continuously monitor and report changes in actual and predicted building energy use. From each house in the sample data from a number of sensors are pre-processed and communicated via Internet. Measured energy use is standardized by statistically regressing energy data against climate data and using climate data for a 'normal' year for determination of average annual energy use for each investigated building. The results are generalized to apply for the studied building stock by using a weighting procedure based on statistical sampling theory. A comparison of results obtained from a pilot study shows that static and dynamic models give similar results although estimates based on dynamic models have smaller standard errors. Comparisons with actual total energy consumption show that the system can give useful results provided that the estimation period contains enough variations in climate.

Keywords: building energy end-use, monitoring, static energy models, dynamic energy models, rotating panel design, climate standardization, Internet-communication techniques

1 Introduction

The need of monitoring building energy end-use

One important use of energy is for the heating of houses and other buildings during the winter. Space heating is a necessity, and it is also a very large item in the overall energy budget in many countries. Of all the energy consumed in e.g. Sweden about 30% is used for this purpose. Although space heating does not require any sophisticated technology, it is an area in which there are real possibilities for alleviating the energy problem through changes in technology. It is also an area in which individual citizens, with their hands on the nation's thermostats and the choices they make in buying, constructing and renovating houses, can significantly contribute towards using energy more efficiently. A large number of energy efficiency improvement measures have also been implemented over the past decades. These measures have reduced the average heating demand per dwelling. In Sweden, for example, total energy use within the building sector is of the same magnitude today as it was 25 years ago although the heated space has increased by 45 % [1].

The energy situation in Sweden is changing with the continued de-regulation of energy markets. In addition national energy programs for re-renewable energies and decisions about energy taxes are to be implemented as a consequence of the Parliament decision to phase out nuclear power and to encourage the introduction of sustainable alternatives. Changes in the general level of energy prices, the prices of particular energy sources and the relation of different energy prices to each other (relative prices) are to be expected. In a free integrated European market for electrical energy, Sweden may export electricity and "import" a high price of electricity from the European continent.

Several other factors e.g. environmental and health concerns together with the technical and economic development will add to the difficulties of predicting and of distinguishing changes in current trends in building energy use. At the same time the economic consequences of these changes are considerable. The present official energy statistics in Sweden provide only crude and partly out-of-date information based on postal questionnaires about building energy end-use and hence methods of monitoring building energy use in order to detect current trends are needed.

The Energy Barometer idea

The Energy Barometer idea concerns monitoring the development of building energy use via continuous energy and climatic measurements in a random sample of houses and reporting changes of building energy use in a short time span. The word 'barometer' is intended to allude to measuring the pressure on the energy market.

The Energy Barometer may be used to determine whether building energy use follows a path desirable for society and building owners or if remedial measures should be undertaken. The construction of the Energy Barometer is based on a combination of modern electronic measurement instruments, data communication and computer intensive statistical methods made possible by the recent technical and scientific developments.

2 Technical Solution

Data handling system

The suggested system for data communication is shown in Figure 1 below. From each selected house the measurements are communicated either by modem and telephone (plain old or GSM) via Internet to the centrally placed Internet service provider (ISP). A new communication device ('Gateway') constructed by Ericsson Radio Systems [2] has been used in a small scale version of the Energy Barometer in 1998. The software for handling the raw data from the sensors are installed in the Gateway which then is connected to Internet via GSM or the telephone net.

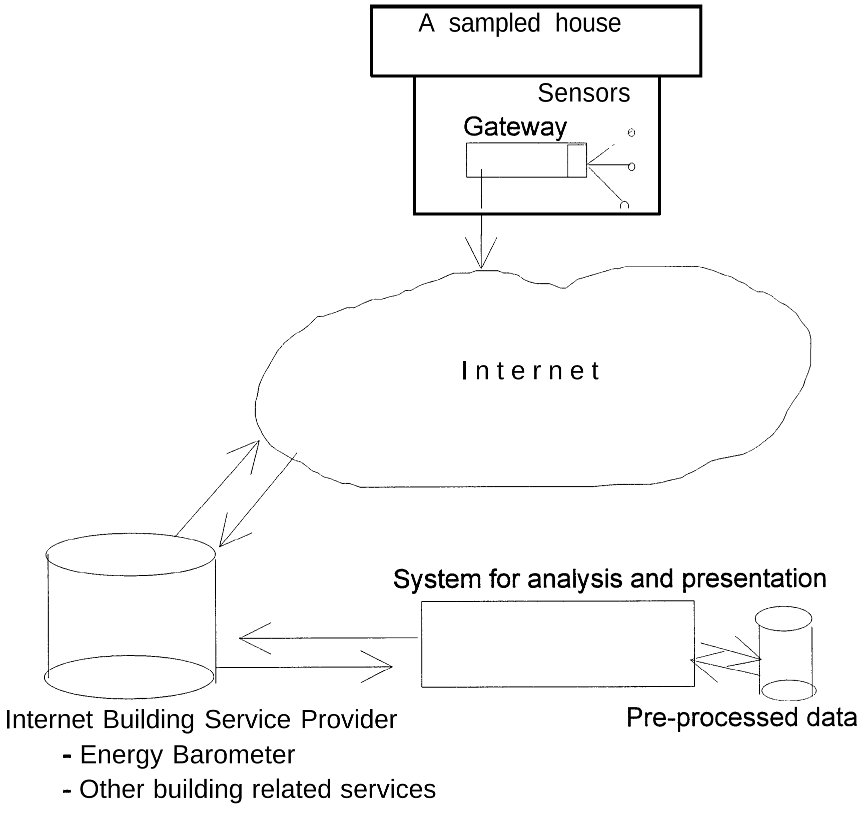

Figure 1. *The data handling and communication system of the Energy Barometer.*

Data needs and measurement design

The Energy Barometer aims at meeting the demands for both accurate and general results by continuously monitoring the following three variables in a reasonably large random sample of houses:

- electrical energy use for household appliances
- energy use for heating, including heating of tap water
- indoor temperature

The main purpose of the Energy Barometer is to give good estimates of total current levels of energy use for heating and changes therein. Therefore the main requirement is that the methods and instruments used give unbiased results with reasonably accuracy.

Table 1. Requirements on measured accuracy.

Variable	Unit	Accuracy	Sensors and additional units
Energy:			
electricity,(electric heating, water borne heating, heat pump)	kWh	± 2 %	kWh-meter with output of pulses
district heating	kWh	± 2 %	integration meter vith output of pulses
oil burner	l	± 5 %	flow meter with output of pulses
Running time: oil	% / h	1% / h	sensor or electromagnetic sond
Temperature: indoor/outdoor	°C	± 0.3 °C	temperature sensor

Basic technical data are collected for each investigated house e.g., number of persons in the household, type of energy source for heating (i.e. electricity, oil and gas, district heating, wood and other bio fuels), heated area, building construction data, electric appliances. Data are recorded on a simple standardized inspection protocol based on interviews and on site inspections [3]. These inspections are performed in connection with installation of the energy and indoor temperature meters.

The measurement designs in the houses differ depending on type of energy source for heating and how the heat is distributed in the house. When e.g., measuring the energy supplied by an oil burner an indirect method is used (see Figure 2). The measured burning time is estimated by dividing the electrical energy used by the burner with its rated power. Then this value is multiplied by the oil flow and the energy content of the oil. The estimated error by this method is approximately +- 6% [4].

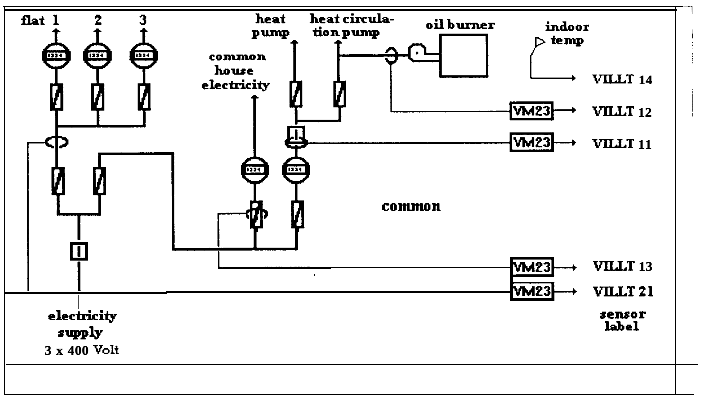

Figure 2. Measurement design in a house with heat exchange pump and oil burner

Weather data are needed in the form of outdoor temperatures and solar irradiation for the measurement periods. These data will be collected from the nearest official meteorological station. Measured energy use is reported in standardized form to apply for a whole year with an "average climate". To this end outdoor climate data are also needed for an "average year" or a so called "normal year" for the different areas where the investigated buildings are located.

3 Statistical Methods

Selection of houses

The initial sample of single family houses is to be selected randomly in three stages. First a stratified sample of some 60 of the 288 Swedish municipalities is selected by probabilities proportional to size. Stratification variables are degree of urbanization and a variable describing geographical location. Then, using the Swedish Property Assessment Register, a stratified sample of single-family real estate properties is selected in each selected municipality. Stratification variable is year of construction. Finally one single-family house is selected randomly from each real estate property.

The whole sample will be selected during the first year. In the following years, one fifth of the sample is replaced annually - a so-called rotating panel design.

The proposed minimum sample size is 700 single family houses. This sample size makes it possible to detect a statistical significant change in energy use from year to year if it is 5% or higher (at 5% level of significance). But for drawing conclusions about changes in sub groups a larger sample and/or additional data are needed.

The results obtained for investigated buildings are generalized to apply for the studied building stock by using a weighting procedure based on statistical sampling theory [5]. Each investigated building is given a weight, which is equal to the number of buildings this particular building represents in the whole housing stock.

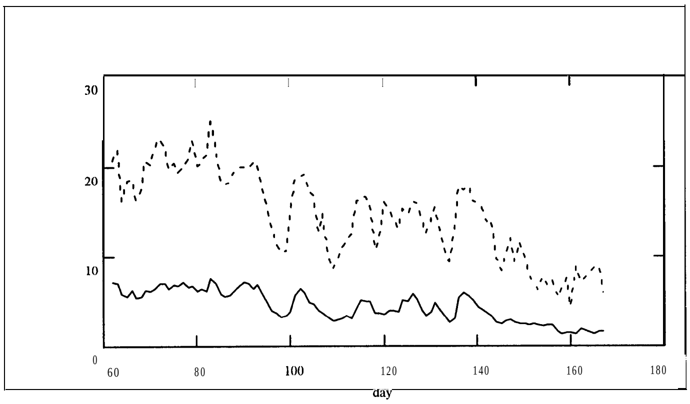

Figure 3. *Energy use for heating (kWh/day; solid line) and indoor-outdoor temperature difference (^oC; dashed line) for a single family house (February-June 1996, Gävle, Sweden)*

Determination of building energy use

The annual energy use is composed of two parts: energy for heating during winter and for heating during summer. The latter consists only of energy for heating tap water.The former depends mainly on the indoor -outdoor temperature difference as displayed in Figure 3 above. Other factors might however also be significant, such as solar radiation, wind and occupancy behavior. Measured energy consumption is standardized to "normal year" conditions by using a sinusoidal approximations of annual daily mean temperature and solar irradiation [6].

The annual energy use for heating W [kWh] in a house during a "normal" year can be calculated as:

$$W = cT + bQ + fI + dP$$

where

c = The 'winter factor' which is the average hourly energy use independent of outdoor temperature and solar irradiation factor [kW]

b = The 'heat loss factor' expressing how well the building stands the outdoor climate [kW/^{o}C]

f = The solar aperture or 'window factor' [m^2]

d = The average hourly energy use for tap water heating during the period when the house is not heated [kW]

T = The length of the heating period (hours)

P = The length of the period when the house is not heated (hours)

I = The solar irradiation during the heating period measured as the global radiation on a horizontal surface [kWh/m^2]

Q = The number of degree hours calculated as T times the average indoor-outdoor temperature difference during the heating season [^{o}Ch]

The energy parameters c, b, f and d have specific values for each house and can be estimated from the measurements using system identification methods. Both static and dynamic models can be used for this estimation see e.g. [7],[8] and [9]. For static models data intervals should be long enough for the heat stored in the building to be very small compared to the total energy supplied (i.e. 24 hours or more). Dynamic models on the other hand can utilize the information embedded in the 'thermal' response of the house to changes in the outdoor climate (e.g. hourly data).

4 Results

The presented technical solution was tested in the first half of 1998 [2] whereas the results presented in this paper are based on a pilot study [3] performed in 1966. The observation period of the pilot study was March - May 1996. Energy use and indoor temperature were observed in four occupied houses. The first half of the period was characterized by relatively cold weather with an indoor - outdoor temperature difference of about 20 ^{o}C and a moderate solar irradiation. At the start of the second half of the period the dynamics of the climate increased with big variations in solar irradiation and a change to higher outdoor temperature. The influence of the varying climate on the standardized estimates was therefore possible to study.

Estimates of similar size were obtained with the simple and more complex static models for both weekly and daily data, but somewhat different estimates were obtained from the first and second halves of the observation period. CusumQ -plots indicated a possible model change for two of the houses both when daily and weekly data are used.

Table 2. *Estimated energy use (MWh) by static and dynamic models in four single family houses (B, F, T and .Y) during the heating period compared to billed average energy consumption.*

	Static model (weekly data)	Dynamic model (hourly data)	Billed average consumption (* estimated)
House B (10 weeks)			
winter heating (MWh)	34.4	35.8	35.0
standard error	12 .	04 .	
adjusted R^2	0.95		
House F (9 weeks)			
winter heating (MWh)	63.4	57.7	60.0*
standard error	2.9	1.7	
adjusted R^2	0.75		
House T (10 weeks)			
winter heating (MWh)	28.5	29.5	30**
standard error	11 .	02 .	
adjusted R^2	0.93		
House Y (53 days ***)			
winter heating (MWh)	20.3	19.1	21.3”
standard error	2.4	0.8	
adjusted R^2	0.78		

** Heated by a combined heat pump and oil burner system (see fig 2) with an estimated total efficiency of about 2.8. 25.3 MWh was supplied to the heat pump and 9.0 MWh in oil to the oil burner. A comparable estimate was obtained as (25.3*3 + 9*0.95)/2.8.
*** static model results based on daily data due to gaps in the data series

The static and dynamic models gave similar estimates of total energy consumption for heating (see table 2). Smaller standard deviations were obtained with the dynamic model. This was expected since more of the information in the data is utilized. One implication is that observation periods can be made shorter when using dynamic models. The results are tentative since we have monitored only four houses for a limited period of time (9-10 weeks).

Models with time varying parameters might perform better than the models with constant parameter systems tested so far. Preliminary results from the analysis of energy data for a longer period of measurement indicate a possible seasonal varying effect.

The estimates agree well with actual total consumption figures. Had we based our estimates on either of the two halves of the observation period this would not have been the case. Therefore, while the search for an improved model goes on, the above methods can be used provided the observation period is long enough to contain representative variations in climate.

Acknowledgments

The results are based on the Pilot study performed in 1996 at the Center for Built Environment, Royal Institute of Technology (KTH). The work was commissioned and financed by The Swedish Consumer Agency and the University College Gavle-Sandviken.

References

1. SOU (1995): *Omställning av energisystemet. Slutbetankande av Energi-kommissionen.* SOU 1995: 139, Naringsdepartementet, Stockholm. (In Swedish).
2. Lindfors A. and Liljestrale M. (1998) *Enforcing energy efficiency measures in the built environment using Internet.* CIB World Building Congress 1998, Gavle Sweden.
3. Westergren K-E., Högberg H. and Norlén U. (1996 revised 1997) *An Energy Barometer for Sweden, Pilot study and Proposal;* Center for Built Environment, Royal Institute for Technology, Gavle. (http://www.bmg.kth.se/www/bmg/baoh/ebaro.htm)
4. Vallenor U. and Wikström L. (1984): *Energiförbrukning i byggnader. Delrapport 4: Mätning av oljeförbrukning och temperatur.* Meddelande M84: 17, The National Swedish Institute for Building Research, Gavle. (In Swedish).
5. Högberg H. and Norlén U. (1991): *De statistiska urvalen i 1991 års energi- och inneklimat-undersokning. ELIB-rapport nr 1.* Rapport TN:24. The National Swedish Institute for Building Research, Gavle. (In Swedish)
6. Anderlind G. (1984): *Approximation of monthly mean temperatures by using Fourier series.* Report BKL 1984: 1 (E), Lunds tekniska högskola.
7. Hammarsten S. (1984): *Estimation of Energy Balances for Houses.* Bulletin M84: 18. The National Swedish Institute for Building Research, Gavle.
8. Norlén U. (1994): Determining the Thermal Resistance from In-Situ Measurements. Bloem H. (ed.): *Workshop on Application of System Identification in Energy Savings in Buildings.* EUR 15566 EN. Joint Research Center, Ispra, Italy
9. Lindfors A. (1995): *Some Aspects of Empirical Building Energy Analysis.* SAVE HELP Working Document; European Community.

Open Building: balancing stability and change

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Abstract

Open Building is an approach to the design, construction and long term management of buildings. It is grounded in principles observed in historic environments which have remained stable while adjusting to new conditions of life. Open Building distinguishes between building parts which can have a log life and those which can change more quickly, and organizes the building process accordingly. The parts of buildings representing long term community values and investments are the parts which contribute a sense of permanence, place and environmental coherence - that are, in a word, sustainable. The short term physical elements represent values of a more individual nature. These are elements which wear out and should be replaced by new and better ones, but which also reflect the autonomy, freedom and the care individuals give to their surroundings.

Open Building is also a set of principles for professionals. With more parties involved, with more sophisticated products, and with more rapid change in all respects, creating stable but changable environments respecting individual differences is increasingly difficult. A key to making sustainability real is an understanding of the life spans of physical and social orders in complex interplay. Open Building offers tools for professionals to use in meeting these challenges.

An example of Open Building is the North American office building. Aside from architectural style, such buildings distinguish between a long term investment - a base building meant to be sustained over time - and a number of shorter term investments comprising the (mostly) interior fit-out for each occupancy. Base buildings do not determine fit-out but offer capacity for variation at a lower level, over time.

However, Open Building is not only for office buildings. It is also for residential and mixed-use architecture. Many residential Open Building projects have been constructed in Europe and Japan during the past two decades, and some have recently been realized in China and the United States. In Europe, an advanced interior fit-out system is on the market for new construction and renovation projects, providing customized residential fit-out at a competitive price. In Japan, dozens of such new initiatives are currently underway. In North America, market trends point to the adoption of residential Open Building in the future, based on the work of pioneering developers in the new construction, re-use and rehabilitation markets.

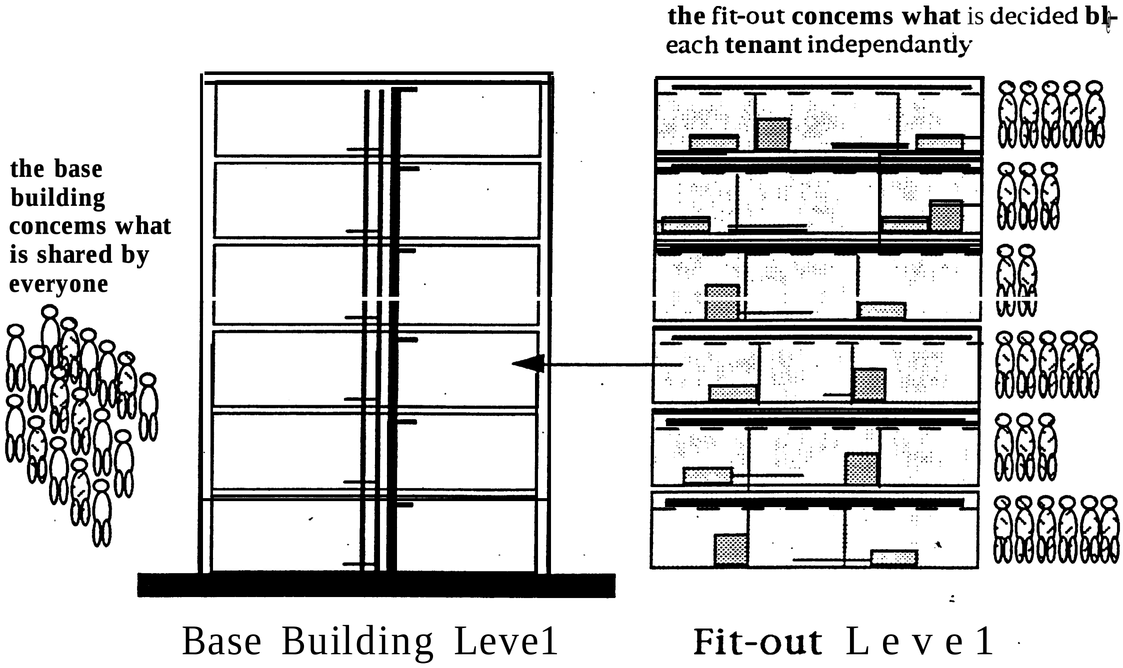
Despite the fact that Open Building is not new, it is not sufficiently discussed or studied. Many problems remain to be solved at both the base building and the fit-out levels and their interface, both technically and organizationally. The implications - and benefits - for all parties are significant. Despite the problems to be solved, this is perhaps the most fertile, wide-reaching basis for advances in sustainable architecture.
Keywords: base building, fit-out, Open Building, residential and non-residential construction, sustainable architecture.

1. Non residential Open Building

For decades, non-residential design, construction and management practice has used and improved Open Building principles. Commercial and retail base buildings in any style and construction type are routinely built without determining interior layouts, and are then fitted out to suit individual occupancies. Older buildings are "revalued" by investing inside - and refitting - existing shells. New "build-to-suit" facilities are designed for the time when the owner will vacate it, making room for other tenants with different requirements for space, equipment and systems.

Construction, manufacturing, cost accounting, building design, management and regulation have adjusted to suit this approach. For example, witness the trend toward complete slab-to-slab fit-out systems in the commercial office market; the increasing use of access floors and modular cabling for adaptable infrastructure; and the increased use of decentralized mechanical and air conditioning systems and controls. In addition, we see a shift in investment patterns in buildings and equipment, first noted in the 1980's (1). To a significant extent, investments are migrating to the fit-out, equipment and furnishings levels of work, with important ramifications for all parties involved.

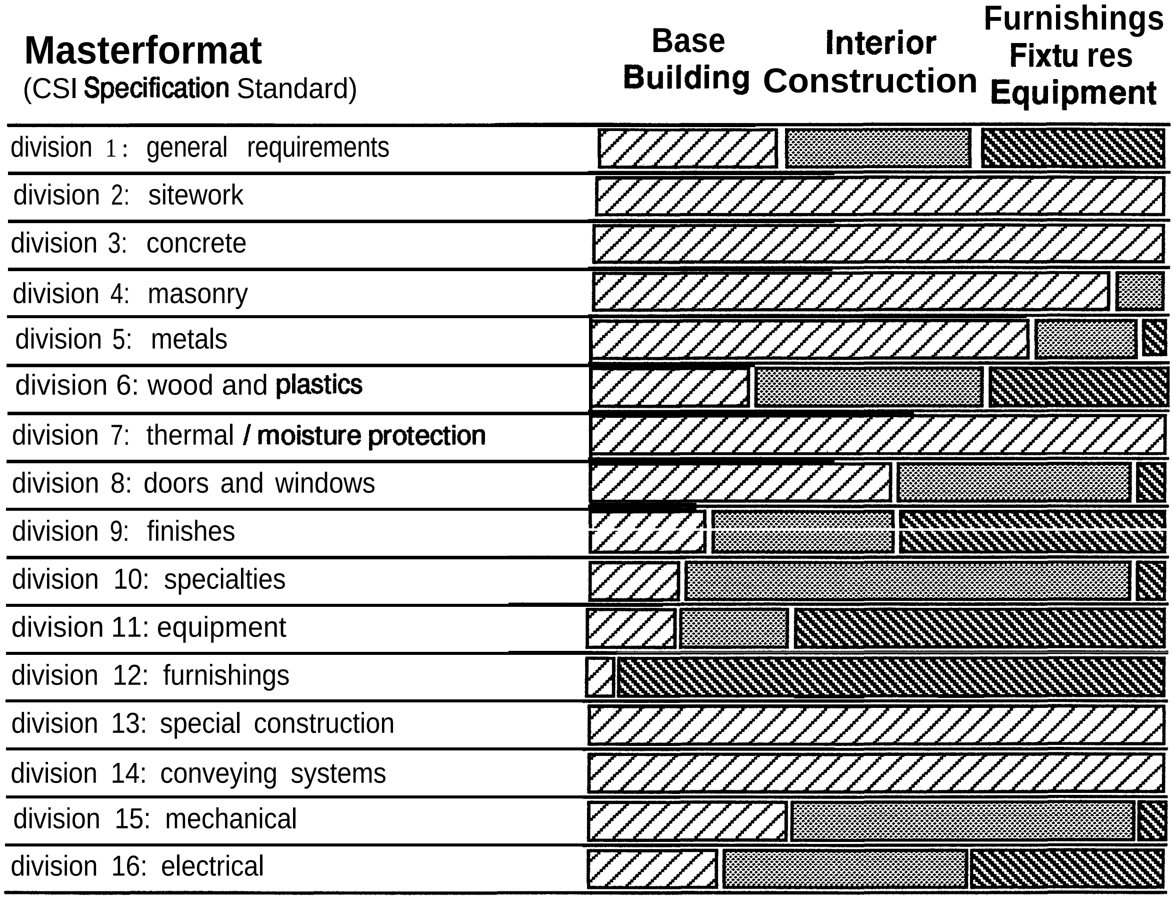
The following diagram shows the distinction between base building and fit-out, emphasizing the close interplay between physical and social realities:



This way of working is pervasive. Building procurement methods and technical terminology have changed to match the separation of levels. Best practices - in use of building systems and organizational procedures - are changing because of the separation of levels.

Another way to see the distinction between the permanent part of buildings and the more changeable is in a diagram based on the Construction Specifications Institute Information Divisions. In the following diagram, both technical subsystems and distribution of control on levels (base building, interior construction and FF&E) are shown together.

Three Tier Model of Control Distribution



In this diagram, each "tier" of control reflects actual distribution of control in most non-residential buildings. Some work is only found in the base building contract, some is principally in the fit-out and FF&E levels, while other work is distributed between all three tiers. Each project will have its own diagram.

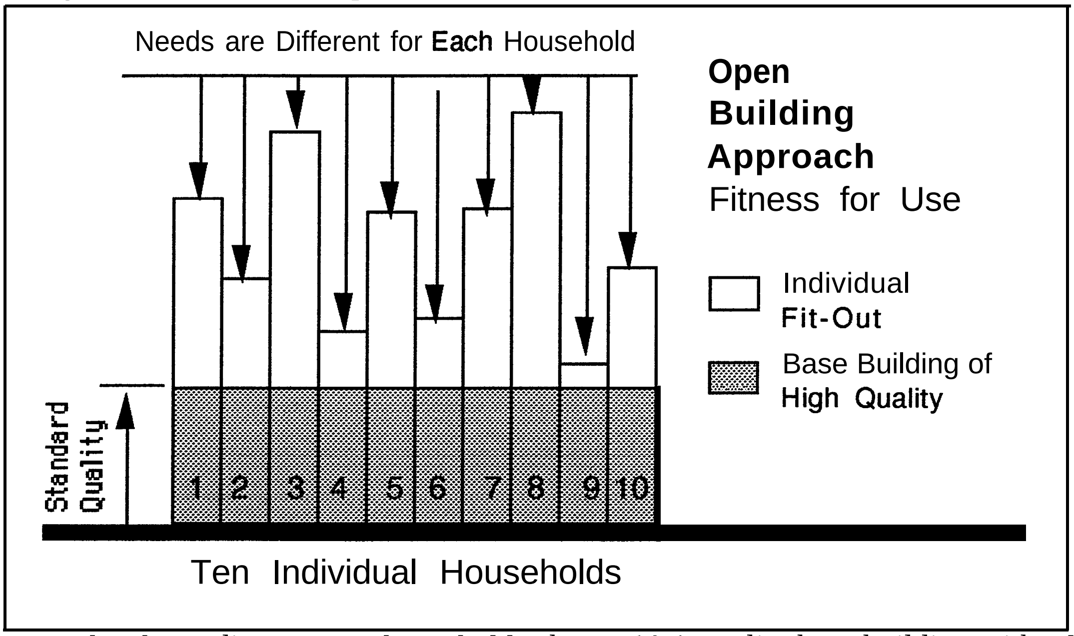
2. Residential Open Building

At the same time that office and retail Open Building has been maturing, many professionals - architects, contractors, lenders, manufacturing companies, government agencies - have been pioneering developments toward residential Open Building, an idea first set out in the early 1960's. (2). In the Netherlands and Japan, for example, the idea of constructing residential "supports" (base buildings) without determining ahead of time the individual layout of dwellings has become increasingly practical(3). Studies (4) and completed projects show that base buildings (supports) can cost less. (5)

For decades, residential Open Building projects remained experimental, hampered by existing development practices and the lack of economically viable "fit-out" or infill systems. Recently, however, development organizations, pension funds and others in the Netherlands who manage large numbers of housing units have begun to discover the advantages of making a sharp distinction between the individual dwelling and the building they occupy(6). With changes in the market in the United Kingdom (7) and the United States (8), a market may be emerging for advanced fit-out systems which enable affordable, customized dwellings in multifamily base buildings - in new construction and in the renovation of older structures.

In part, these developments in the market are founded on the recognition that natural diversity - in income and make-up - so familiar in many urban neighborhoods which have matured over decades - is an important goal both in social policy and private investment. Open Building is a way to accomplish this goal: variety is more costly - and is more equitable and socially desirable - than uniformny, a reversal of long held assumptions.

The following diagram (9) indicates this principle: Open Building offers a solution by distinguishing the more enduring, common part of a building from the more changeable, individualized part:



In the above diagram, ten households share a high quality base building with a long life. Each individual can have a fit-out suited to its budget and preferences. The base building has the capacity for a sustained relevance, while the fit-out can remain in place as long as it matches the priorities and preferences of individual households. The basic unit of social life - the household - can now be matched by the way the building is organized in respect to community values. This is in contrast to normal residential architecture in which the individual unit is largely subjugated to the needs of the whole, producing a rigidity out of touch with the natural diversity of a modern society.

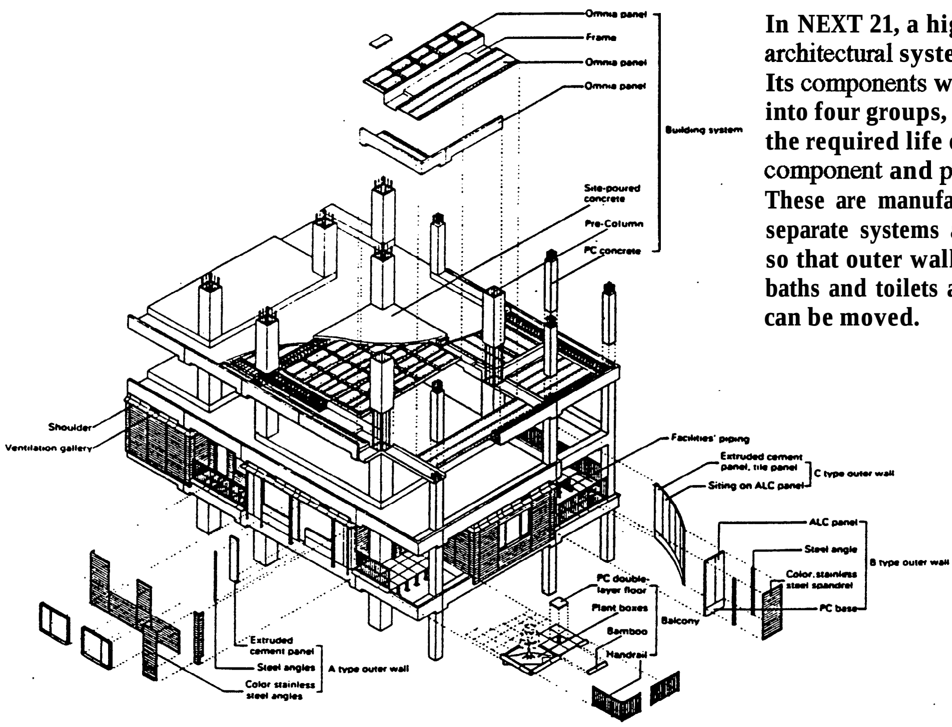
3. Examples of Open Building projects

In Japan, private corporations, the Ministry of Construction and its Building Research Institute, the national govemment's Housing and Urban Development Corporation, the Minisby of International Trade and Industry, and local Housing Authorities are setting the trend. They are investing to implement Open Building as part of a widespread effort to replace the "build, scrap and rebuild" pattem with a new approach to sustainable environments. Many dozens of projects have been built and many more are planned, each breaking new ground.

The most advanced project in recent years is the NEXT 21 project in Osaka, completed in 1994.(10) Sponsored by Osaka Gas Company, it is an experimental mixed-use project designed to come to terms with urban living in the next century. It focuses on issues conceming the right mode of housing in a changing society: where lifestyles are becoming more diverse; where the information society is becoming more advanced; where the problems of natural resources and pollution countermeasures that come with increased energy requirements become more severe; where houses are needed which can adapt to changes in society and lifestyles.

One architect designed the building's framework and infrastructure; another designed the facade system; and **13** other architects each designed an individual house, using the basic frame and infrastructure and the "kit-of-parts" facade system.

NEXT **21** is currently being modified and monitored. One unit was recently altered including its exterior facade and bathroom and kitchen location. Thus, the building acts as a living laboratory of advanced technology and energy conservation processes.



In NEXT 21, a highly flexible architectural system was used Its components were divided into four groups, according to the required life of each component and production path. These are manufactured as separate systems and modules so that outer walls, kitchens, baths and toilets and gardens can be moved.

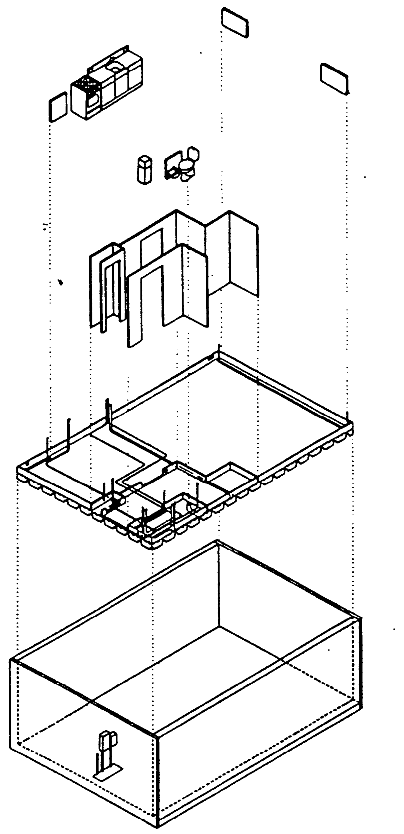
NEXT 21 Experimental Housing Project in Osaka, Japan

In Europe, a major German Company will soon begin routinely using a residential infill system developed in the Netherlands. The same product is already being used in multifamily rehabilitation and new construction projects in the Netherlands.

This infill system is a so called "open system". Given an empty shell, Matura® offers a fully prefabricated and adaptable infill system for residential construction. It includes spatial partitioning, as well as all technical subsystems, and kitchen and sanitary equipment, providing a fully equipped and habitable dwelling unit. **(11)**

It utilizes subsystems and parts that are readily available on the market like wall systems, doors and door frames, various finishes, as well as kitchen and bathroom equipment. It can accommodate new developments of such off-the-shelf products. All these subsystems are integrated into an adaptable whole my means of two newly developed elements: the "Matrix Tile" and the "Base Profile". These new elements provide flexibility in design, fast installation on site, and changeability in the future.

In a typical renovation project, removing the old apartment's elements may take two weeks, during which time the new plans are made and the technical work of preparing the infill package commences at an off-site facility. Days later, the package arrives in one or two containers, accompanied by a trained team of 3 or 4 multi-skilled people who complete the installation in another 10 - 14 days. Because the system is pre-approved, no building inspectors must be scheduled for site visits. It is, therefore, a completely new and unique and product for residential architecture.



The Matura Infill System fits in any given physical context. Installation does not pose special demands on the base building or the facade. Thanks to the free distribution of pipes, ducts, conduits and cables, the position of vertical shafts does not determine floor plans. This makes the Matura Infill System particularly attractive for renovation projects.

Schematic of the Matura Infill System

In Finland, rehabilitation of 30 year old multifamily buildings following Open Building practices is starting.(12) In the United Kingdom, a number of private companies and government ministries are actively engaged in Open Building developments, both for new construction and renovation.(13)

In China, work is moving beyond experimental projects (14) to wider applications. Open Building is becoming more popular though a variety of terms are used: "empty shell" houses; two-step houses; adaptable houses. More significant, the Open Building concept has been accepted by the authoritative bodies such as the Ministry of Construction as a major direction in the development of housing technologies.

For the time being, North American residential development does not follow Open Building principles, except for a few high end condominium projects which nevertheless do not have the benefit of a comprehensive infill system. (15) While we understand the historical reasons' for this reality, evidence from other countries and from current trends in North America suggest that we should - and ultimately will - also adopt Open Building in our residential architecture. Already, an American timber frame home builder is committed to Open Building in its operations.(16)

4. A watershed period for architecture

Such developments - in residential and non-residential work - are of major significance, even though they are not yet recognized for their merits. We are without doubt experiencing a watershed period of change. To facilitate exchange ofinformation and to support implementation, CIB (the International Council for Building Research Studies and Documentation) has formed a Task Group on Open Building. Members come from around the world from the design, construction, manufacturing, regulatory, lending, and academic research fields, and meet twice each year, in different countries to discuss their work, organize studies, and otherwise collaborate in implementing this approach to sustainable man-made environment. Its web site is www.decco.nl/obi

5. Open Building as a way toward sustainable architecture

The basic principles of Open Building are aligned exactly with the goals of sustainability in buildings and man-made environment for several reasons.

First, sustainability rejects throw-away cultures where buildings are made to last only a short time. Equally important, sustainability argues for investment incentives aimed to align long and short term values in the use of real estate assets.

In Japan, and in other countries with large central government building programs, the result of throw-away incentives was the "scrap and build" tradition in which buildings were rigidly constructed based on then current standards, quickly became obsolete, and were then found to be too entangled to bring gradually up to date. Now, this investment strategy is rejected in favor of a "stock" approach, in which emphasis is placed on maintenance programs and building for change.

Open Building offers a strategic contribution to the question of long term vs. short term. By making a clear distinction between the parts of a building that should last for 100 years and the parts that should - and realistically cannot - last so long, it is possible to accurately account for value and responsibilities, and to decide clearly about longevity of a building's subsystems. The separation between a base building - designed for capacity for change - and the fit-out - designed for individual freedom and for a shorter span of use - enables all parties to balance long and short term priorities.

Second, Open Building supports the development of "click-together" components with high re-use value. This has direct bearing on sustainability. Too much of the fit-out of office buildings, for instance, is discarded upon reconfiguration of space, in part because it is priced without accounting for embodied energy or "cradle to grave" costs. But equally important to the problem is that even the higher value-added components - too expensive to become throw-away products - are not easily reusable in new circumstances because interface standards have not yet maturred.

Open Building has a goal of "manufacture and design for assembly, disassembly, and reuse". This means that product manufacturers will make products compatible with other products having tight interfaces, but which are made by other companies. For instance, Molex's cabling and power distribution system used in Haworth office fumiture is not compatible with Steelcase's equally sophisticated wiring system used in its own office fumiture. But product compatibility in building subsystems made by different manufacturers is inevitable. Open Building provides tools to help achieve this.

A Regionally Adapted System for Assessing Building Performance

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Abstract

The development and structure of a second-generation system for assessment of energy and environmental performance of buildings is described. The system is being developed in a process that involves 14 national teams in the adaptation of a core framework to suit regional conditions. Performance benchmarks are developed for three generic building types, schools, office buildings and multi-unit residential buildings. The system has been developed in a computerized format and the structure will be made available to interested organizations.

The system is being tested in 1998 on a minimum of two projects per country and results will be presented at an international conference in late 1998.

Keywords: environmental assessment, international, regional, energy, framework, testing

1. Introduction

The testing and labelling of buildings is in its infancy and there is no consensus yet on the range of performance characteristics that should be covered, nor how much rigour needs to be applied in the application of such a system.

However, it is clear that there is increasing interest in some sort of robust and validated system that can provide comprehensive performance assessments of buildings.. Further, there is a need for a model that can encompass the wide variety of physical conditions, building traditions and environmental priorities that occur in different countries and in regions within countries. This paper describes the features of a model that has been designed through an international collaborative process to meet these objectives.

2. The Green Building Challenge Project in Brief

Before getting into details and issues, it will be useful to have a short overview of the project, called Green Building *Challenge'98* (GBC '98). It should be noted that GBC '98 consists of two related elements: a two-year process of developing and testing a performance assessment model, called Green Building Assessment Tool (GBA Tool), and an international conference to mark the end of this process. The overall goal of GBC '98 is to test and demonstrate an improved method for measuring building performance, and then to inform the international community of scientists, designers and builders about the results. The project was initiated by Canada, but is being carried out in partnership with representatives from thirteen other countries.

Specific objectives of GBC '98 include:

- To develop a second-generation method for assessing building performance, with an emphasis on energy and environmental performance;
- To develop the method through an international and collaborative process;
- To test the system on buildings in each participating country; and
- To report on the results of the process in an international conference.

International projects are always expensive. Why, then, has this ambitious project to develop an environmental performance assessment system been launched, especially when several systems already exist?

There are several reasons, but the one most relevant to this paper is the nature and limitations of the existing first generation environmental performance assessment systems. We will provide a quick overview of only three of these in this paper.

3. Existing Performance Assessment Systems

BREEAM
The first and most widely known is the Building Research Establishment Environmental Assessment System (BREEAM) [1], which is jointly operated by the Building Research Establishment (BRE) and a private firm, ECD Ltd. The BREEAM system has now been adopted in a number of countries and is reportedly used to assess some 15% to 20% of new office buildings in England.

BEPAC
Another first-generation system is the Building Environmental Performance Assessment Criteria (BEPAC) system [2], developed at the School of Architecture, University of British Columbia. The developers had the advantage of having BREEAM as a prior model, and the result is that BEPAC is more detailed and comprehensive than the first BREEAM variants, although BEPAC is limited to office buildings.

LEED
The U.S. Green Building Council (USGBC) funded by NIST, has launched a system designed specifically for use as a green labelling system for rating the performance of commercial office buildings. The system [3], known as Leadership in Energy and Environmental Design (LEED), is very simple in its structure in that all criteria are placed at the same level of importance. However, the criteria in the system are linked to a series of existing performance standards established by other credible bodies, which is an asset. Also, an elaborate management system has been established to implement it and several major industrial suppliers are strong backers, which give the system a significant chance for widespread adoption in the U.S.A.

Design limitations of existing systems
Although the BREEAM, BEPAC and LEED systems are all ground-breaking initiatives, there are some factors which are likely to limit their widespread application, including their difficulty in handling different levels of detail in assessments, and the difficulties resulting from attempts to use them as design guideline instruments. For the purpose of this paper, however, the most relevant problem is the

difficulty encountered in adapting these systems for use in different regions and countries.

For example, although we can compensate for climatic differences in analyzing the energy performance of office building in Zurich with one in Toronto, it would be misleading to directly compare the normalized results, since large differences in energy costs underlie a large number of decisions made by the owners and designers with respect to systems used and levels of performance sought.

Regional differences are not confined to energy costs and climate. The European building tradition places greater emphasis on daylighting and access to operable windows, which make the deep floor plates typical of North American practice unacceptable there. Can we therefore meaningfully compare the inherently more energy-efficient shapes of North American office buildings with their European counterparts?

Even cultural differences come into play. Office workers in Japan and Europe are more willing to accept short-term deviations from a thermal comfort envelope than are their North American counterparts, and this can have major implications for the designed capacity of heating or cooling systems.

In summary, our view is that regional differences are of such significance that meaningful performance assessments must take them into account from the outset. This results in the use of locally-valid benchmarks of performance, so that an assessment is more a reflection of improvement within the region rather than the production of a set of results that can be compared across countries or continents. The trade-off is that some information relevant to international performance benchmarks may be lost, but at least one can be sure of the validity of the regionally-based results.

In the GBC '98 assessment framework, an attempt is being made to develop a system that addresses these requirements.

4. The GBC '98 Development Process and Framework Structure

The process being followed in the development of GBC '98 can best be described as an international partnership. Canada took the lead, but the other thirteen participating countries are making substantial staff and financial contributions, and have a decisive influence on the development of the system through their participation in the International Framework Committee (IFC), the committee that contains representation from all participating National teams.

The design of the framework began in the summer of 1996 and underwent several iterations in its design, based on extensive feedback from the IFC. At the time of writing (December 1997) the framework and software, called GBA Tool, has been completed and national teams are about to start testing the system in their own countries.

The GBA Tool is designed to be modifiable by national teams, based on their interpretation of applicability to local conditions. It includes the following elements:

- Parameters descend in generality from Performance Categories to Criteria and, at the most detailed level, Sub-Criteria;
- a scoring system has been established that ranges from -2 to +5, with the 0 (zero) level being the reference level;
- the performance level required to achieve a certain score is based on the 0 (zero) level being the locally relevant reference or industry norm level; a -2 is significantly inferior and a +5 is set so that is extremely difficult to reach;
- each parameter contains written statements related to each relevant score so that assessors can relate the actual performance to the nearest relevant statement, and National Teams can modify these statements within limits;
- weighting is possible at both the sub-criterion and criterion level, again modifiable by National Teams;
- criteria and sub-criteria can be declared critical at the option of National Teams, and failure to meet a critical level can disqualify the subject building;
- versions of the system are being prepared for each of three major building categories, including office buildings, multi-unit residential buildings and schools. These were selected by the IFC as representing some of the most generic building types extant, thereby maximizing the value of international comparisons; and
- the GBA Tool system is being implemented in the form of two distinct software modules; a Green Building Input (GBI) module, and a Green Building Assessment (GBA) module. These modules are being developed within a user-friendly database program. Conceptually, the system is relatively simple, although both modules include some calculation fields. The software system is also intended to facilitate the work of National Teams in specifying the characteristics of hypothetical reference buildings to serve as benchmarks, and in modifying scoring statements and weighting values.

The completed framework covers issues that are given in-depth assessments down to the level of sub-criteria. These include four *Resource Consumption* categories, four *Environmental Loadings* categories and five categories relating to *Quality of the Indoor Environment..* Other sections deal with *Longevity,* Process and *Contextual Factors,* which are assessed only at an upper (Criterion) level. The current organization reflects the view of the IFC that in a process with limited time and resources, there is a need to focus the detailed assessments on factors that are most germane to the goals of the process, e.g. resource consumption, environmental loadings and health/comfort issues.

5. Future Applications

The presentation of the results of this ambitious process at the GBC '98 conference in October 1998, should be not be viewed as an end-point. We may be closer to achieving consensus on what factors collectively constitute excellence in environmental performance, but it is likely that much further work will be necessary to position the system as an implementable system in the industry. Givkn this, it is likely that the process will continue and that a GBC 2000 conference will take place in another country.

In addition, work will begin this fall to extend the system so that it can serve as a related guideline system for building designers and developers. The GBA Tool could be pressed into service for this purpose, but to make it a fully effective guideline system many specific recommendations will have to be prepared that relate to each assessment parameter.

Given that there is need and potential demand for an assessment system, how could such a system be launched? Existing systems such as BREEAM, BEPAC and LEED were developed to serve the specific requirements of the context in which are used and have invariably been tempered by the necessity to meet the compromise of stake-holders and the practicalities of implementation. Each of these methods will continue to evolve and mature. The GBC '98 assessment framework will offer new assessment methodologies for them to consider and, if they so desire, to use.

However, if a consensus emerges that the system provides a substantial improvement over current systems, there may be a desire to implement GBC '98 or GBC 2000 as a complete stand-alone system for commercial building performance assessment. If this occurs, there are a number of desirable organizational features that should be considered:

- the body that develops and continues to improve the system should establish links with one or more recognized standards bodies;

- agencies that implement the system should be quite separate from the development agency;
- the development agency should be in a position to certify that implementing agencies are "100% pure GBA Tool" in terms of their system structure, procedures and staff training requirements; and
- the high cost of developing hypothetical reference buildings to serve as benchmarks will have to be reduced; possibly by developing a library of off-the-shelf stock reference buildings or benchmarks based on archetypes of common building types and forms.

6. Conclusions

The development of the core GBA Tool is now complete, but it will only be possible to evaluate success or failure after national teams have gone through the process of adapting it to their own conditions and have tested it on several projects each. Considering the effort, resources and collective expertise of the sponsoring countries that is going into its development, however, it is likely to at least make a substantial contribution to the state-of-the-art.

7. Acknowledgments:

The principal technical consultant for GBC '98 is Dr. Raymond Cole of the School of Architecture, University of British Columbia, and the software has been developed primarily by Woytek Kujawski of Inpol Consulting Ltd. The following individuals lead their respective national teams and have also greatly contributed to the development of the GBC '98 framework:

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Roger Baldwin, UK
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Drury Crawley, USA
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Philippe Duchene-Marullaz, France
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Susanne Geissler, Austria
Mauritz Glaumann, Sweden
Werner Hässig, Switzerland
Nobuyuki Kimata, BCS team, Japan
Gail Lindsey, USA
Günter Lohnert, Germany
Aleksander Panek, Poland
Michiya Suzuki, IBEC team, Japan

8. References

1. Prior, J. (Ed) (1993) *Building Research Establishment Environmental Assessment Method,* (BREEAM) Version 1/93 New Offices, Building Research Establishment Report, Second Edition.

2. Cole, R. J., Rousseau, D., and Theaker, I.T. (1993) *Building Environmental Performance Assessment Criteria: Version 1- Office Buildings,* The BEPAC Foundation, Vancouver, December 1993.

3. U.S. Green Building Council, (1996) *LEED (Buildings: Leadership in Energy and Environmental Design), Environmental Building rating System Criteria,* Third Ballot Draft, 30th April 1996

9. Appendix Sample of Scoring Statements from GBA Tool - for Operating Energy Consumption

Score	Default Performance
-2	The annual operating energy per m^2 of net usable floor area of the case-study building is 45% GREATER than that of the Reference Building.
-1	The annual operating energy per m^2 of net usable floor area of the case-study building is 20% GREATER than that of the Reference Building.
0	The annual operating energy per m^2 of net usable floor area of the case-study building is EQUIVALENT to the Reference Building.
1	The annual operating energy per m^2 of net usable floor area of the case-study building is 25% LESS than that of the Reference Building.
2	The annual operating energy per m^2 of net usable floor area of the case-study building is 40% LESS than that of the Reference Building.
3	The annual operating energy per m^2 of net usable floor area of the case-study building is 55% LESS than that of the Reference Building.
4	The annual operating energy per m^2 of net usable floor area of the case-study building is 65% LESS than that of the Reference Building.
5	The annual operating energy per m^2 of net usable floor area of the case-study building is 70% LESS than that of the Reference Building.

Modelling cash flow in construction projects in countries in transition

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Summary
The paper describes the modelling of cash flow in construction projects in countries in transition. Data of construction contribution in investment is shown, as well as GDP and total employed personnel in Croatian construction industry. Analysed are the most important changes which affect construction in a country in transition as well as those changes which affect the modelling of cash flow.

In the central part of the paper, the effect of risk and time slacks on the ability to form theoretical curves of cost flows is analysed. Results of research related to the effect of risk on time and cost, performed on 100 randomly chosen construction projects, are presented. The main sources of risk are described. The analysis of the effect of risk is performed with the aid of interpolation of various curves for costs between planned and actually recorded cost curves on the observed projects. Testing for each individually obtained curve for costs is performed through the bestfit approach with 18 theoretical functions. Ranking is performed according to the Chi-square and Kolmogorov-Smirnov tests. The analysis shows that the effect of risk increases the interval of possible shapes of the cost curves and the various possible forms of best approximation. The testing of the effects of reserves for completion also indicates various possible deviations from "a single curve". From that then, this paper proposes the creation of a value interval instead of a single theoretical curve. In order to ensure a practical value of results, proposed are criteria by which projects can be grouped.

The concluding part of the paper discusses possible application of modelling of cash flow in connection with possible directions of development in a particular country in transition. For example in Croatia the emphasis is oriented on tourism, which like most human activities affects the natural resources which acted like a base for its development. From this then, the paper discusses the need for the development of a model of sustainable development, which includes a balance between commercial success of a project and environmental protection. In the calculation of cash flow it is necessary to include costs of protection of natural resources, but according to a model which protects and unites the interests of investors, government and institutions of environmental protection.
Key **words:** cash flow, country in transition, construction projects, risk, development

1. Cash Flow

Data related to monetary transactions is not complete if it does not indicate time duration along with cash amounts. Planned cash flow is, therefore, equally important for all partners in construction projects. From the early phases of projects up to the time of contract signing, no partner has the necessary information for the creation of a precise plan for billing or payouts of money. The flow of cash is exceptionally difficult to determine ahead of time due to the influence of a large number of variables which give an unlimited interval of possible profiles. With an insufficient amount of exact information, every partner relies on estimates based on personal experience attained on previous similar structures. Complete repetition of previous steps is acceptable if measures and factors are the same on both projects. In this case it happens seldom, so precision in planning calculations is not guaranteed.

During recent years, certain methods of prediction and modelling of cash flow profiles in projects have been developed. All approaches are generally based on the use of certain mathematical formulas and computers. The product is usually a profile with the shape of an S-curve which shows the cumulative value with weaker beginning and ending growth rates in phases of work start-up and finishing. Developed models follow the same concept of cash flow development. That is, the difference of cash in and cash out originated through the conversion of cumulative value curves and cumulative cost commitment curves, using time delays and retention [1] . The primary emphasis of the research is placed on the creation of ideal curves for the various types of projects - Bromilow & Henderson 1977 [2], Hudson 1978 [3], Singh & Won 1984 [4], Tucker 1988 [5], Skitmore 1992 [6], Kaka 1996 [1]. The importance of past researches have been pointed out by various authors [8, 9], but there still remain various opinions about the level of precision of the proposed methods.

2. Construction in economies in transition

Development and construction activity in previously socialist countries was significantly determined by political ideals. In the former Yugoslavia, politics favoured large industrial projects and massive residential building. This was primarily due to the political idea that every worker must have a permanent job and a flat in which to live for a minimal cost. Together with permanent investment in infrastructure, that insured the construction industry in Croatia a portion of about 50% in investments and about 10% in GDP, and 8-10% of all employed people worked in the construction industry [IO] . Like the other industrial branches, construction had insured employment and market through required government support in cases of poor functioning of some company. So, for the evaluation of the success of a construction project, emphasis was placed on the technical correctness and functionality of a structure, while cost and time were not primary criteria for the evaluation of success. Methods of evaluating and keeping record of cash flows in construction projects were only partially used.

There are few examples in modern history where such a large amount of significant changes occurred in a short period simultaneously like in Croatia: war, creation of state, change in social organisation, change in the economic system and a shift to a market economy, privatisation,. . . For the construction industry, the following changes are especially significant:

1. Reduction of investments and employment in construction.
2. Insufficient capital in companies.
3. Absence of government support in cases of poor performance.
4. Opening of the market for foreign competition.
5. Significant reduction of the number of employees in large companies, with simultaneous changes in the structure of employed personnel in favour of production workers and the opening of a large number of smaller companies.
6. Change in the ownership structure of the company in which significant shares are taken over by groups of individuals, therefore, a change in the manner of managing and decision making.
7. Removal of non-construction and secondary activities in the structure of the company.
8. Time and money spent on construction and later on maintenance of the structure become important criteria for evaluating success.

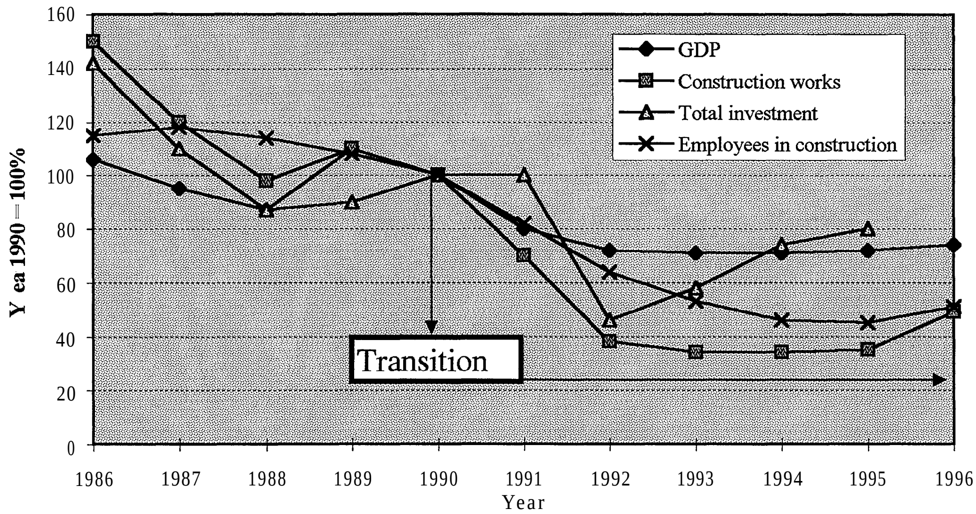

Fig. 1: GDP, investment, construction works and employment (1990. y. =100%) [10]

In each of the mentioned changes the significance of money, which is much in demand on the market, was emphasised. The way money is managed becomes a key factor for success for individuals and companies, and, therefore, for the general economy in transition. Planning and control of cash flow in construction projects becomes exceptionally significant for every contractor and investor.

3. Influence of risk on cash flow

The formula which was most commonly used for predicting cash flow in construction projects was the one published by the Department of Health and Social Security in Great Britain [3]. That is one formula with which it is necessary to use a series of pairs of parameter values for the creation of the correct curve for a project of a particular size. The DHSS formula was tested by numerous researchers with the goal of improving and simplifying it. Skitmore 1992. [6] analysed the DHSS formula on 27 completed construction projects grouped into four basic types. Research into various models for predicting best values for parameters shows that they are all equally productive, and that well grouped structures significantly improves the quality of forecasting. Tucker 1988 [5]. proposed an alternative form and use the Weibull function with seven parameters. Kaka and Price 1993. [8] performed research on about 150 completed construction projects, who's individual and group analyses determined that cost commitment models are more accurate and reliable than value models. Kaka 1996 [1] proposed a model with a large number of variables and stochastic simulation which includes analysis of the effects of risk. Taking into consideration results of previous research which indicated that the shape of a curve depends on the sum of costs [5], type and size of project, and type of contract [6, 8], we have attempted to look into additional effects - especially risk and activity time slacks.

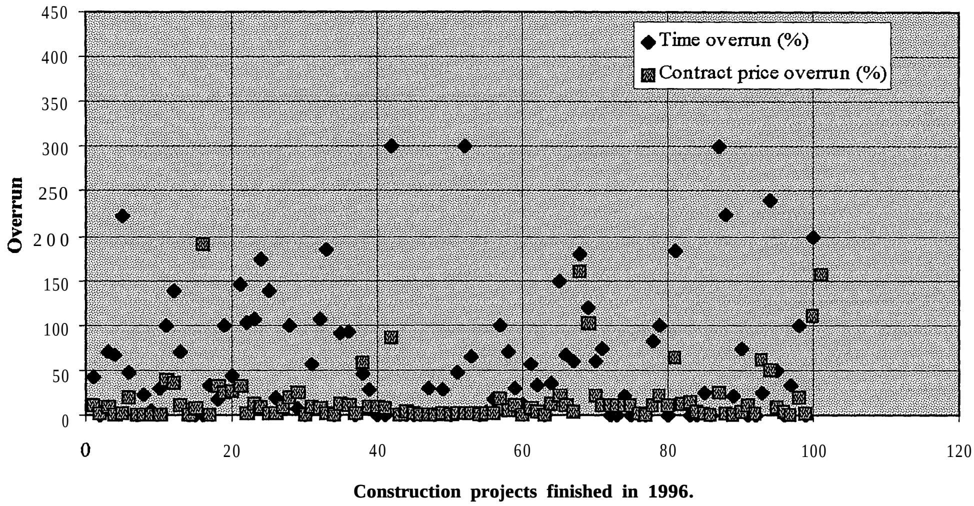

Fig. 2: Occurrence of overruns of planned times and planned money in samples of construction projects in the year of 1996.

Our beginning research [11, 12] consisted of creating project plans for a large number of construction projects. Curves of planned costs were then constructed from these project plans. At various points of completion, status control was exercised and data was collected. With the data it was possible to:

1. Construct an actual cost curve.
2. Perform further forecasting for a planned curve at individual points of completion.
3. Analyse the causes of deviation between planned and actual cost curves.

For modelling cash flow especially significant are results related to deviations between planned and actual cost curves. Research into 100 randomly chosen construction projects showed an average of 66% overruns in planned times and an average of 1'7% overruns in planned costs [13], with about 18% of extreme cases with a time overrun of over 100%. Added research in the year of 1997, with data from 1996/97, shows that overruns of planned times occurred in 74% of projects, and overruns of planned costs in 69% of projects. Research shows that in about 2/3 of construction projects there exists a general trend of problems with overruns of planned times and costs. The analysis of risk indicates that a dominant portion, 58%, of risk is from internal sources which have causes rooted in the project. That shows that although there exists a problem of large changes in the transition market, individuals and companies that adapt too slowly to the changing global market are largely responsible for project shortcomings. Five dominant sources of risk according to occurring frequency are climate, local permits, poor project preparation and participant optimism, unsolved financing of the project and incomplete technical documentation. The analysis of sources of risk in a transitional market like in, Croatia, indicates that according to occurring frequency criteria and degree of negative influence on planned time and cost goals in construction projects, the dominant problems are unrealistic and overoptimistic planned goals and unsolved financing along with various forms of limitations.

The effects of risk are a significant factor which creates differences in cash flow in construction projects. Risks cause differences even between completely similar projects, so it is therefore difficult to group projects by particular criteria and automatically have similarities in cash flows. For the analysis of effects of risk we have performed an interpolation of various cost curves between planned and actually recorded cost curves on observed projects. We took into account that initial plans were overoptimistic and varied the effect of risk. Testing of individual obtained cost curves was performed through the bestfit approach with 18 theoretical functions [14]. Ranking was done according to the Chi square and Kolmogorov-Smirnov tests. Analysis shows that with increased elimination of effects of risk normal distribution becomes dominant, however, if risk is included in projects then variations in results are increased.

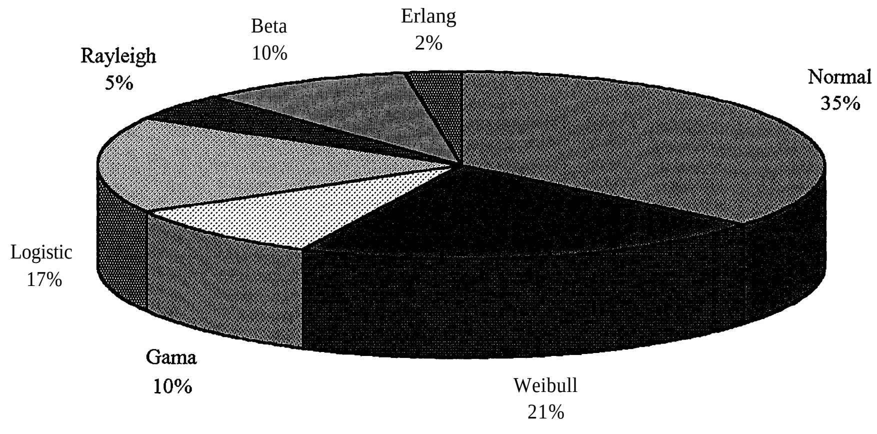

Fig. 3: Results of bestfit approach - rank according to Chi square test - minimal risk effects included

Performed research indicates that:

1. Effects of risk significantly influence the possible shape of cash flow curves.
2. Considering the impossibility of eliminating all risks in a project, or the ability to exactly forecast all risks in early phases of projects, research shows that the precision of individual theoretically obtained curves is questionable. It is, therefore, better to determine an interval of possible values instead of attempting to predict exact individual values.

4. Influence of time slacks on cash flow

The other significant factor affecting the shape of cost flow curves is the allowance to complete certain activities at various times. The use of network planning techniques enables the identification of noncritical activities who's planned completion is always within the area of "Early Start" (ES) - "Late Start" (LS). In practice, this means that instead of one specific cost flow curve it is possible to construct an area of cost flow with boundaries ES and LS curves. All values within the boundary area are possible and represent completion according to plan. Reserves in completion an activity time are positive in every case of management, and contractors closely study them during preparation. From this point of view as well, then, it is also difficult to determine one particular curve which will absolutely represent cash flow in a construction project.

On Fig. 4., shown is the area of LS cost flow curve for a group of projects concerning small tourist structures with 4 floors and an average completion time of one construction season and an average price of construction works of 1.5 mil. DEM (without furnishings). In comparison shown is cost curve obtained through the application of theoretical formulas from literature [5], for which it can be said that it probably represents an interpolation within ES and LS areas.

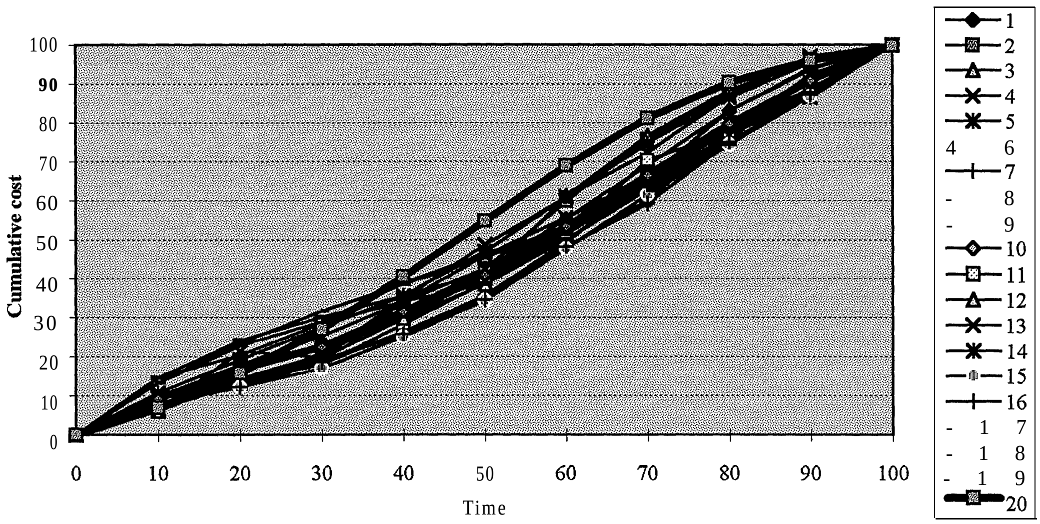

Fig. 4: Examples of cost curve areas for late start and minimal effects of risk (19 = average sample for late start Weibull(l.92 ; 0,60); (20 = theoretical Weibull curve (1,98;0,53) [5] ;)

The area between curves 19 and 20 might represent an interval of probably values for cost curve in this case, with included minimal effects of risk and no final time and cost overruns . Using results of our work and work done by other researchers, for a practical application we have adopted an approach which dictates that for determining cost flow curves, boundaries of curve group intervals should be set. In order for results to have practical values the interval has to be sufficiently narrow. This is achieved by grouping projects by numerous similarity variables:

1. Similar technical characteristics of structures.
2. For costs in intervals up to 1; 1-2; 2-4; . ..(mil. DEM).
3. For project duration in intervals up to 0,5; 0,5-1; l-2; 2-3, more than 3 (years).
4. In conditions of control or effect of similar primary sources of risk.
5. Same type of contract.
6. Same size of contractor.

5. Sustainable development and cash flow planning in economies in transition

The motive for a new project in every economy is the desire for development and profit. In an economy in transition these wishes are even more evident but at the same time are limited by a shortage of cash for investment into development. During the socialist era, development was carried out in the name of development through which the success of political ideals was proved. Through political and economic changes, countries in transition are trying to follow economic laws of market economies in order to achieve a standard and level equal to that in developed countries. In this approach, complete copying of development paths and development of the same areas could be contraproductive. Economies in transition have to follow their own development path in which the speed and quality of development will be harmonious. It is precisely the quality of development which points toward a need for orientation in the direction of traditional resources and wealth of a country in transition. An alternative to secondary or unclear production which is simply transferred from developed countries can be found in modelling of sustainable development. For example in, Croatia, this could be an emphasised orientation on services in which tourism development dominates. Tourism is a significant factor in development plans in many countries in transition. Culture, history, and natural beauty can serve as an excellent base for the development of tourism if the safety of tourists and acceptable prices and quality of service can be guaranteed. However, like most human activities tourism has consequences that affect the base which determines its initial development. This implies a spiralling reduction in natural resources: scenery, water,. . . A high level of information, a conscientious plan of environmental protection and the monitoring of laws and bylaws in developed countries enables countries in transition to make good decisions on time. In the case of tourism this is controlled sustainable development, in which at the project planning phase it is necessary to include plans for protection of natural resources.

In, Croatia, research looking into air and water pollution control, and solid waste disposal is being developed. Some results for example indicate that it is possible to solve the solid waste problem of the tourist area of the southern Adriatic coast in, Croatia, with a yearly investment of about 4 mil. DEM [15]. With cash flow modelling, or economic parameters of projects, it is possible to find a model for parallel tourism development and environmental protection. Since investors are significantly burdened with expectations of maximum profit, and, hence, minimum costs, it is probable that local and government authorities will have to control the process. This could happen through permits, concessions, regulations, laws, bylaws, and a system of penalties or benefits. That is an important co-operative effort between the investor, government, and institutions which ensure environmental protection. Success primarily depends on the modelling of an acceptable cash flow solution in projects according to balanced criteria settled by all parties involved.

6. References

1. Kaka A.P. (1996) Towards more flexible and accurate cash flow forecasting, Construction Management and Economics 14, 3 5- 44.
2. Bromilow F. J & Henderson J.A. (1977) Procedures for Reckoning and Valuing the Performance of Building Contracts, CSIRO Div. of Building Research, Highett
3. Hudson K. W. (1978) DHSS expenditure forecasting model, Chartered Quantity Surveying Quartile, 5, 3, 42-45
4. Singh S. & Woon P.W. (1984) Cash flow trends for high rise buildings, Proceedings of the International Symposium on Organisation and Management of Construction, University of Waterloo, Canada, pp 841-854.
5. Tucker S. N. (1988) A single alternative formula for DHSS S-curves, Construction Management and Economics 6, 13-23.
6. Skitmore M. (1992) Parameter prediction for cash flow forecasting models, Construction Management and Economics 10, 3 97-4 13.
7. Singh S. (1996) Cash flow trends for infrastructural works in residential developments, Shaping theory and practice (vol. 2) E&FN Spoon, London.
8. Kaka A.P. & Price A.D.F. (1993) Modelling standard cost commitment curves for contractors' cash flow forecasting, Construction Management and Economics 11, 271-283.
9. Harris & McCaffer (1989) Modern Construction Management, BSP, Oxford.
10. Statistical yearbook of Croatia, 1994.,1995., Statisticki zavod RH, Zagreb.
11. Izetbegovic J. & Radujkovic M. (1996) Research on projects realisation trends, Proceedings of international symposium "Information systems 95", University of Zagreb, Varazdin 1995, p. Bl-5.
12. Simic T. & Pejovic T. & Radujkovic M. (1997) Information system for planning and control of cash flow in a project, Proceedings of international symposium "Information systems 96", University of Zagreb, Varazdin 1996, p. 161- 169.
13. Radujkovic M. (1997) Risk sources and drivers in construction projects, Management risks in projects, E&FN Spoon, London, 273-283.
14. Bestfit, Palisade Co., N.Y., 1995.
15. Milcic J. (1997) Solution to the problem of solid communal waste from Makarska to Dubrovnik, Gradevinar 49, 4, p. 195-201.

Open Industrialisation: State of the art and future perspectives

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Abstract
All technological development, and building technology even more so, is bound to the general development of society. Globally, societies are at very different stages of development: early industrialised ones are rapidly moving into the post industrial information era, while developing countries still are at the very start of industrialisation. This is one reason why possibilities for industrialisation differ between countries and from one region to another.

In industrialised countries the advanced industrialisation of building technology is necessary to meet the requirements of economy through increased productivity and general life cycle sustainability, including quality for users and ecological aspects. State of the art analysis has shown that the industrialisation rate in building is highest in countries where open industrialisation is applied. This is because of increased competition between suppliers who can exploit the high increase in productivity in factories through product development. Organisationally, open industrialisation supports a horizontally integrated production and networks which are becoming increasingly international. Special technologies may even be global. However, building concept applications and individual building designs must be local thus respecting local cultural and architectural traditions. In all industrialised countries, particularly in earlier socialistic ones, a clear change from the image of mass production time is necessary. Computer assistance and computer aided communication are provide crucial support to advanced technologies.

In developing countries the significance of locality is very strong, and because of a lacking general industrial environment manual working methods are expected to dominate well into the future. Also important is the use of local materials and products.

Much research work is still needed in the development of products, management, design and manufacture, as well as assimilation of the research results into knowledge through education.
Keywords: Building, industrialisation, open, productivity, future perspectives, state of the art, research needs.

1. Background and current state

Building production world-wide is a vast business arena with great importance for the entire welfare of the people, for the economy of organisations and companies, and for general sustainable development of societies [1, 2, 3]. Building technology, even more than other technical sectors, is closely linked to the development of the society as illustrated in Figure **1.** [2, 3]. This is why the possibilities of building industrialisation differ widely from country to country. In early developed countries the prerequisites are good for industrialisation, while in developing countries several social and economical factors still prevent it.

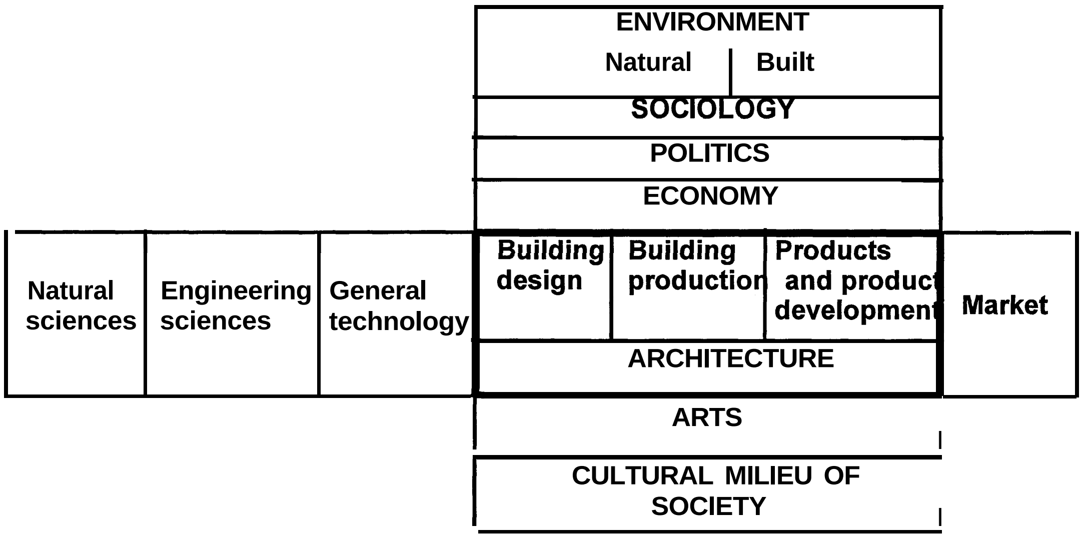

Fig. 1. The development environment of building technology /2/.

The societies in most developed countries have already passed from the industrial era into the post-industrialised information era, whereas newly industrialised (NIC) countries are at a fast developing phase of industrialisation and developing countries are at the very start of it.. However, even in early industrialised countries building production has been developing somewhat slowly towards industrialised production, lagging behind e.g. the automotive, shipbuilding and mechanical industries by as much as two generations. This is one reason why buildings for housing and for business and industry are usually expensive and production is sensitive to recession.

It is being recognised that the slow increase in productivity of the building sector has already led to increasing costs, and that therefore the building market in developed countries lies in a long term stagnation phase. An important tool in re-activating the building market is the reduction of price levels. In the NIC countries the need for building is high and the main prerequisite for effective industrialisation is an increase of production capacity.

During the mass production era of the 1960s and 1970s the production requirements dictated town planning and architecture at the expense of social and aesthetic considerations of both buildings and built up areas. The technical quality was sometimes insufficient, and especially poor in socialistic countries, which has led to generally negative attitudes towards industrialised building. Consequently many traditional prefabricated building systems still exist, which apply mostly the principles of closed or semi-closed systems (Warzawski) [S].

Advanced open system building is dominant in some countries like Finland, the Netherlands and Denmark. In several countries, such as Japan, France, Germany and the USA, closed company-wise applications dominate. In the countries where open systems are dominant, the market share of modern industrialised production is high, whereas in countries with closed systems the rate of industrialisation is considerably lower. This indicates that open systems strongly undergird industrialisation [1]. In countries with open industrialisation, today industrialised building means the exchange and application of products, services and information between the players in the building process, nationally and internationally, and between countries and regions with major differences in the structure of the building industry (Adler) [5].

2. Principles and definitions of open industrialisation

In order to meet economic requirements together with other requirements like aesthetics, functionality, ecology, durability, health and comfort of living, we have to rethink the entire content and solutions of industrialised building. Increasing international exchange of technology and building products could activate industrial development through increasing competition and evolution with the help of a continuous selection of the most competitive technologies and products. This requires international openness of building, product and information systematics, because only in this way will we activate and accelerate the internationalisation trend. Buildings play a major role in defining the local culture of our built environment. Therefore even international technologies and products must be highly adaptable to both local traditions and the natural environment. Industrialised building is not an objective in itself, but has to be understood as a tool for sustainable production of buildings for housing, working, leisure and industrial production. Openness is a road to all kinds of co-operation between the partners of building. The required openness refers to the capability to assemble products from alternative suppliers into the building and to exchange information between users, clients and partners of the building process and inside the consortia and business networks.

There are many different terms and definitions for open industrialisation [1]. Some are presented in the following.

Today the industrialisation of building means the application of modern systematised methods of design, production planning and control as well as mechanised and automated manufacturing processes /2, 3/.

Open system building is a general framework for the building industry, including modular systematics of products, organisation and information, dimensional co-ordination, tolerance system, performance based product specifications, product data models etc., so that the suppliers serve products and service modules that will fit together /2, 3/.

Openness is a concept with many aspects, like [1].

- OPEN for individual designs
- OPEN for competition between suppliers
- OPEN for alternative assemblies
- OPEN for future changes
- OPEN for information exchange
- OPEN for integration of modules and subsystems.

The central scope of open industrialisation includes the following areas /1/:

- Demand Side, dealing with user requirements and with the introduction of the requirements into designs.
- Supply Side, dealing with the production requirements and with the linking of -- demand and supply.
- Building Process, including organisation and communication in building projects.

A system is an organised whole consisting of its parts, in which the relations between the parts are defined by rules. The parts can be concrete (e.g. the components of a building system) or abstract (e.g. the components of an information system) [2, 3].

An open modular system consists of modular parts at different hierarchical levels, for which it is possible to produce different interchangeable products and designs that can be joined together according to connection rules to form a functional whole (Sarja) [2, 3].

In a dimensional coordination system, the reference system consists of planes, the intersection of the planes (lines) and the intersection of the lines (points). (de Troyer) [7].

A cis aspect which is seen (a) to limit the market for the parts to the market of the whole, and (b) to constrain the freedom of decision-making of the system participants, notably the architects (Davidson) [4].

3. Future perspectives of open industrialisation

3.1 Open industrialisation in industrialised countries

The current most advanced technology is flexible to individual architectural designs also allowing easy alterations during use, future changes, and modernisation. For this aim, systematic modular design and products are applied, including dimensional modulation, tolerance system, compatible joints and modular products disposition. As technical tools, highly mechanised and automated methods are increasingly applied to the manufacture of components in factories as well as in assembly and some phases of on-site manufacturing. Computer aid is increasingly applied throughout the building process: in analysis, design, manufacturing, production and operation. INTERNET is serving as a rapidly growing support for communication both locally and globally.

Future perspectives of open industrialisation in building are promising, because there exist several driving forces in general development of societies, which are pulling the development into the industrial way. Such kinds of driving forces are e. g. the following:

Future perspectives of open industrialisation in building are promising. Several driving forces in the general evolution of societies are pulling development in an industrial direction. These include:

1. A global need for increased productivity in the building sector, in order to cut production costs in developed countries and raise production capacity in developing and newly industrialised countries. Statistics show a drastically higher growth of productivity in factories yielding building products than at site works (Fig. 2)
2. Growing demand for guaranteed quality. This is best fulfilled in industrial and automated production both in developed and in developing countries.
3. The increasing goal towards sustainable development in building. This is best solved in industrialised countries through industrial production, which saves energy and materials, and where wastes can be recycled better than in manual production on site. However, in the least industrialised countries an alternative solution can be a very local production in manual methods using local natural materials.
4. Loss of manual skills in industrialised countries. This trend continues and threatens the building sector unless modern methods and industrial ways of production bring skilled workers into the building sector.
5. Reluctance of workers in industrialised countries to work in harsh and/or unsafe site conditions. This is already creating a shortage of workers at a time of high unemployment.

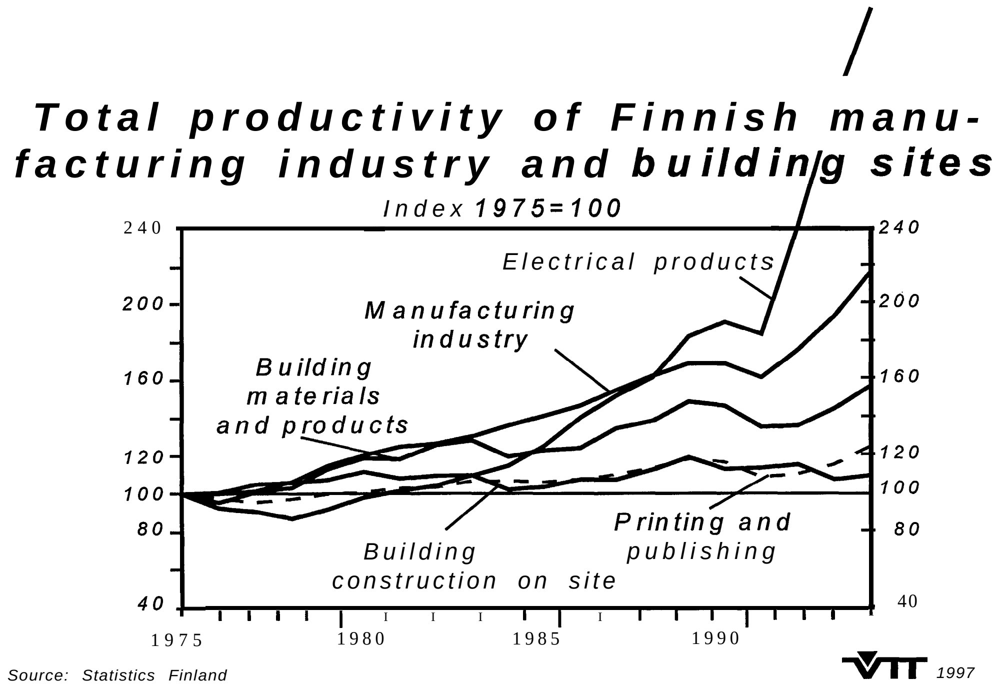

Fig. 2. Development of productivity in factories of building materials and products compared with construction sites and other branches of industry.

Industrialised building technology is developing globally and internationally, but applications into building concepts and designs must be made very locally in order to fulfil the local cultural, environmental, operational and economical requirements (Sarja [2, 3, 4], Weber [4]. . Individual buildings have to be adapted to the needs of their owners and users.

General industrial principles and methods can be applied in building [2, 3, 5]. Open industrialisation can be developed as a global technology which can then be applied regionally and locally in different ways using locally and regionally produced products and materials. The general rules and models can be concretised into building concepts for defined consortia or networks of contractors and suppliers.

In all subareas an important task is the transfer of generic principles and models from other fields of technologies into building, and participation in applied technical research in the core areas of industrial technologies. Such research areas include e.g. the STEP systematics of product modelling and several IS0 standardisation works regarding technical specification systematics. Open computer aided design systematics includes design organisation and rules enabling exchange of data in real time between partners. The openness includes the rules and systematics of general data bases, of data structures in design and of standard data interfaces between the partners (Fig. 3.).

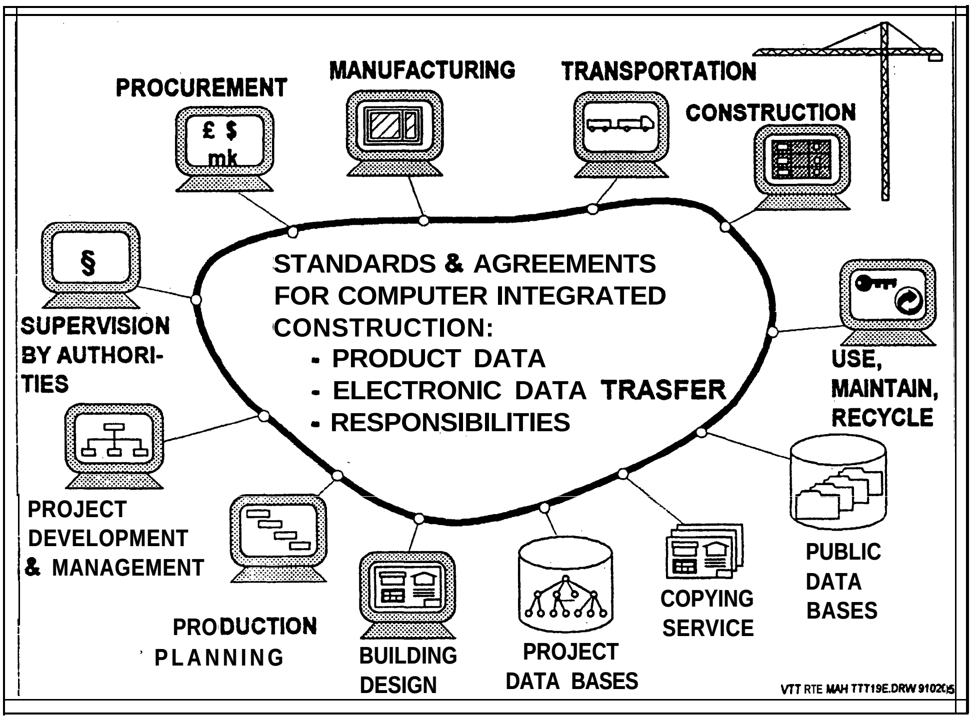

Fig. 3. A general scheme of open computer integrated construction [3].

It has been proposed that future open industrialisation in industrialised countries should be concretised through horizontally integrated production — mainly through the open building system and open design in horizontally integrated companies marketing alternative, mutually compatible deliveries (materials, components, modules, assemblies and services) for contractors or clients, thus fostering competition [3]. However, the contractors each apply the systematics to their own building concept, which means a closed business network.

The building process is moving from current sequential production toward parallel production, where several phases of manufacture are carried out parallelly and simultaneously under control of the project management (Sarja) [2, 3] (Fig. 4).

A special case among industrialised countries is the former socialistic countries, where a rapid collapse of industrialised building followed in the wake of changes in the society. Prefabrication is still regarded as a symbol of socialism; the quality is considered too low and the appearance extremely monotonous. This image is expected to prevail for a long time and to be a significant barrier to effective development of industrialised building. Another factor against industrialisation is the continued focus of building and development on renovation. Once this is satisfied through radical technical and architectural changes, the recovery of industrialisation is both possible and likely.

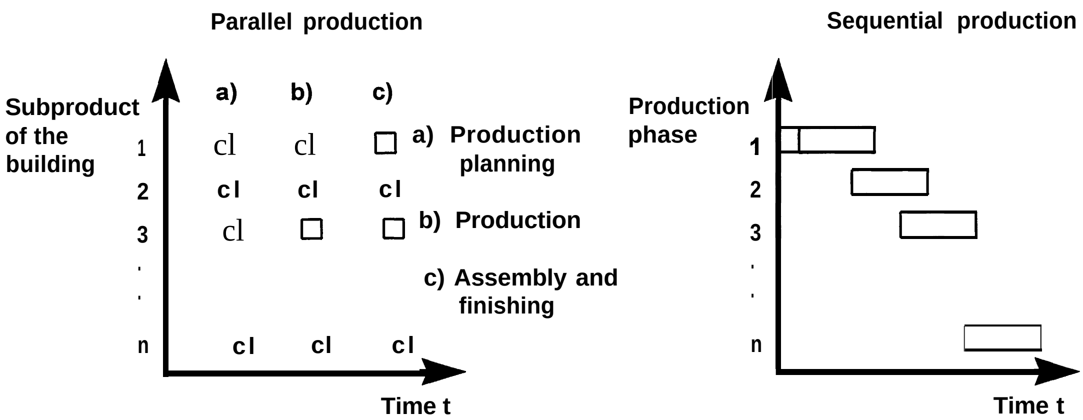

Fig. 4. Schematic presentation of parallel and sequential building production.

3.2 Newly industrialised countries

Newly industrialised countries tend pretty much to follow the development trends of the 1960s and 1970s, which were characterised by mass production. However, the technology now applied is better developed, and more open and flexible systems are used. There is now a good opportunity for newly industrialised countries to develop their production infrastructure, organisation and management, and design and product systematics with application of open industrialisation and general industrial methods. They also have the advantage of being able to learn from the mistakes of countries which developed sooner.

3.3 Developing countries

In developing countries it has been recognised that building technology and housing development must follow ways which are related to local traditions as well as social, environmental and technical possibilities. Thus the development of industrialisation, although certainly expected to continue, will be slower and different from that in the developed countries.

4. Research and development

In order to accelerate development of international industrialised building technology, research should be directed at further systematisation of performance concepts and of modularised system rules in product systems, organisation systems and information systems. The systematics should be presented as model designs, alternative organisational models and applied product data models. It is important to identify and analyse productivity factors and use the results to develop methods for improving productivity.

For implementation of the results into practice, companies have to develop long term strategic development projects over 5 to 10 year periods. These should include overall business strategy, product and method strategy and information system strategy.

The strategies should be followed by development of business networks and consortia and definition of the building concepts for them. These building concepts can be described and tested through model designs and experimental building projects

5. Acknowledgements

I am privileged to have the possibility of working as a coordinator in CIB W 24: "Open Industrialisation in Building", which discusses state of the art future perspectives in this branch. I would like to thank those members of W 24 who contributed their expert evaluations and reports to the state of the art project, as well as the great number of authors to whom I refer in this study.

References

1. Sarja, Asko (Editor), Open and industrialised building. Manuscript, accepted for printing by Chapman&Hall, SPON Co, to be printed in June, 1998.Part I (author: Asko Sarja appr. 90 p.+ Part II (Several authors): appr. 80 p.
2. Sarja, Asko, Principles and solutions of the new system building technology (TAT). Technical Research Centre of Finland, Reserach Reports 662. Espoo, Finland, 1989. 61 p.
3. Sarja, A. & Hannus, M. Modular systematics for the industrialized building. VTT publications 23 8. Technical research centre of Finland, Espoo 1995.2 16 p.
4. European Communities Commission. Stuttgart February 21-23, 1990. Open industrialization a solution for building modernization. Conference proceedings.
   Davidson, C.H. Open industrialization: Technical and organizational prerequisites. Pp. 4-17 - 4-26.

Hannus, M., Computer aided design of component based building.pp.6-1-6-10.
Sarja, Asko, A new generation of open building based on hierarchical modulation. Pp. 6-21 - 6-30.
Weber, J., The advantage of open industrialisation and dimensional coordination for developing countries and for the opening of regional market. Pp. 7-11 - 7-22.
5. Sarja, A. Towards the advanced industrialized construction technique of the future. Betonwerk + Fertigteil-Technik 4/1987 pp. 236 - 239.
6. Adler, P. CIB-W24: Open industrialization in building, State of the Art in Sweden. 1996. 9 p.+ app. 6 p. In Report of CIB W24 meeting, November 6-7, 1995. The University of Reading.
7. De Troyer, F. Principles of modular co-ordination in building. Draft for revision by IMG/CIB W24. Katholieke Universiteit Leuven Departement ASRO Kasteel van Arenberg B-3001 Heverlee, Belgium 30. June 1991.
8. Warzawski, A. Industrialization and Robotics in Building. A Managerial Approach. National Building Research Institute Technion-Israel Institute of Technology. 1990 New York. 466 p.

ENVIRONMENTAL CONCERNS FOR CONSTRUCTION GROWTH IN GAZA STRIP

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Abstract :
Gaza Strip region is a fragile ecosystem suffering from increasing environmental assaults due to the escalating population growth and the very limited natural resources available to support their development demands. Currently, there are a number of large scale construction projects being implemented in the process of newly developing Palestine. Environmental impact assessment of the proposed projects should include the social and economical dimensions. The major challenge in the development context is to maintain ecological balance which is often sacrificed when rapid economical growth is pursued putting enormous pressure on the natural endowments. This implies search for innovative and new building materials and construction technology in order to minimize the pressure on environment. The aim of this paper is to study the impact of rapid construction development on the environment in Gaza Strip. It is strongly recommended that Palestine should follow a program to promote sustainable development through the building of better institutions, and providing appropriate information and investment. It is necessary to assess the impacts of the proposed projects in Gaza Strip and to take certain measures to mitigate the negative impacts. There is a need for raising environmental public awareness and training.

Keywords: Ecosystem, sustainability, construction, emergency development.

1. Introduction:

In Palestine, environmental problems are dominated by the absolute need to better manage limited natural resources to meet the needs of its population. Such a population which is not only growing at a rate of 4.2% annually but also is adopting new life styles and consumption patterns which are more environmentally demanding. The fact that the population / resource variables are set on a collision course imposes the urgent environmental imperative of containing excessive population growth, and dictates a development strategy based on a more efficient use of limited physical resources (1).

Engineering team and construction contractors are responsible for the resource demands of the environment they create, on the other hand owners and occupants are accountable for the waste products they produce. Buildings have to be designed to take into account ecological principles, such as the reduction of pollution, sustainable growth, recycling of waste and energy, energy effectiveness and conservation of resources (2). The design of infrastructure projects in Gaza Strip needs a sensitive analysis of environmental requirements, but the process of procurement, construction and operation also need careful judgment and development. Consultant engineers and manufacturers need to develop a green ethic which encourages donors and developers to plan a project in an environmentally friendly way.

Disputes still exist about environmental issues with respect to their causes, effects, acceptable levels, and the desirable measures. However, there is a basic agreement on the need to monitor the situation, seek to understand the complex processes involved and adopt suitable strategies. Most countries now follow the concept of sustainable development. They seek to ensure that economic growth is achieved without eroding the resource base, causing pollution or upsetting ecosystems (3). Analysis, synthesis and evaluation of social, economic, as well as technical issues, will be vital if a holistic approach for producing environmentally responsive buildings is to be achieved.

Building and construction in Gaza use scarce land and utilize many physical inputs. Their products are used for most productive and social activities and owing to their durability, continuously interact with the physical environment. Construction can be a vehicle for effecting schemes for protecting the environment. Environmental issues are seldom considered on construction projects in Palestine because of the emergency nature of the projects. However, most donors like the World Bank and EC require environmental impact assessment study during the planning stage for most projects in order to be considered.

The purpose of this study is to consider the implications of the increasing concern with the environment for construction industry in Gaza Strip.

2. Geographical Background:

Palestine, as it stands now, is divided into two distinct regions covering a total area of approximately 6,183 square kilometers (6 million dunums). These regions comprising the inland region known as the " West Bank ", The coastal region known as the " Gaza Strip " and the proposed " corridor " connecting the inland and coastal regions.

The inland region has a maximum length of 137 kilometers a long the longitudinal axis between Zububa in the north and the southern most boundary line south of Al Samu. Its width varies from 31 kilometers along the latitude connecting Jerusalem with the northern tip of the Dead sea, to 58 kilometers along the latitude starting from Qalqilia along the western boundary and intersecting the Jordan Rever north - east of Zubeidat. The total population in the West Bank is estimated at approximately 1.6 million.

The coastal region, Gaza Strip, is a semi - arid coastal land of roughly 240 kilometers of arable land along the eastern Mediterranean Sea, the total area is about 365 square kilometers. It has an average maximum length of 45 kilometers between the boundary near Beit Hanoun in the north, and Rafah on the Palestinian - Egyptian border in the south. Its width varies from 6 kilometers along the line transferring through Deir El - Balh in the center, to 13 kilometers along the Palestinian - Egyptian boundary in the south. In this narrow strip, almost 1 million of the Palestinian people live and work. There are 575.000 refugees in the Gaza Strip, of which about 32.000 live in eight refugee camps. The population density in the camps is one of the highest in the world and varies from 30.000 to 100.000 persons per square kilometer.

The proposed connecting " corridor ", which is essential to ensure territorial integrity and viable socio - economic integration, has an area of around 136 square kilometers and extends from Idna in the south - west of the inland region to Beit Hanoun in the north - east of the coastal region. It has a total length of about 35 kilometers and an average width of 4 kilometers.

3. Environmental Situation:

Environmental conditions in Gaza appear to be among the worst in the Middle East. Serious environmental problems exist in several sectors, e.g. water, wastewater, and solid waste. Successful economic recovery will require effective integration of environmental, cultural and tourism resources into the development process. In Gaza Strip there are more than 500 industrial units which dispose their waste (solid and liquid) either into improper sewage systems or on the ground, causing pollution of the soil with organic and inorganic chemicals and other pollutants (4).

The major source of air pollution is the exhaust of about 30.000 to 35.000 motor vehicles, most of which are more than 15 years old outdated. The exhaust contains large quantities of carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbons and lead that are detrimental to the respiratory and nervous systems (5). Domestic and agricultural solid wastes are dumped freely, with the resulting leachate adding to the ground water pollution. Some of the wastes are burned, causing air pollution.

Fresh water is a scarce resource in Gaza. The main water resources are the coastal plain aquifer and the water transmitted from other locations. The quality of the ground watering the Gaza Strip is poor. Water quality is deteriorated due to infiltration of sewage, solid waste leaches and agricultural chemicals. Water quality in Gaza fails to meet international guidelines (chloride content 200 - 1000 mg/1, 77% of wells with nitrate concentrations greater than 50 mg/1 and 44% greater than 100 mg/1) while although water quality in the West Bank is generally satisfactory at present, sewage infiltration creates local problems (6).

Sewage ponds, and the Mediterranean Sea are used for the disposal of domestic, agricultural and industrial waste water. More than 50% of the raw sewage is discharged untreated into the sea, causing sever water pollution. Most areas in Gaza Strip still have unsatisfactory waste water collection and treatment system, there is great reliance on septic tanks, cesspits and percolation pits that are usually designed to serve a single home or a small group of homes. These alternatives require frequent discharge by vacuum tankers, and also pose a great threat to ground water (7).

In Gaza City the sewerage network only covers 65% of the residents. While the villages of Jabalia, Beit Lahia, Beit Hanoun, and Nazla are currently being connected to sewerage systems, only waste water collected from Jabalia and Nazla is transferred to Jabalia treatment plant. Some residents in Rafah are connected to a sewerage system which pumps the collected waste water from the Tel El - Sultan pump station to a lagoon in the area.

Per capita water consumption in the Gaza strip is expected to increase due to the housing and building projects which aim at extending the water supply network and providing a rather continuos supply to the customers. Many locations in the Gaza Strip suffer from broken water supply where they receive water for a few hours per week. the projects which purpose to provide a sewage collection network will also cause an increase in the domestic water consumption. The reason is that many houses face a problem in disposing off their wastewater due to the use of unsealed vaults of a limited capacity (8).

The rapid growth of population and development in the Gaza Strip have contributed to the magnification of solid waste problems. Estimates of the quantities, composition and density of solid waste produced by Palestinians is still very limited, with estimates ranging between 1.4 and 1.7 liters per capital daily. It is further estimated that up to 60% of this waste is organic (9). Table 1 shows the composition of solid wastes in Gaza Strip. Currently, solid waste management is the responsibility of the Palestinian municipalities and village councils, The United Nations Relief and Works Agency (UNRWA) has been responsible for services necessary for the refugee camps (10).

Table 1: Composition of solid wastes in Gaza Strip

Composition	by wet weight %
Organic Materials	67%
Paper	1.5%
Metal	1.5%
Glass	1.5%
Cloth	1.5%
Plastic	2%
Sand	23%
Other	2%

(source : UNRWA, 1993)

In many areas, solid waste is left in near by fields, abandoned plots and streets creation dangerous odors and providing breeding grounds for pests in the summer time, especially mosquitoes and rats. No system exists for collecting and disposing of waste from construction sites. Stones debris and powder resulting from stone processing are scattered throughout the countryside. The impact of poor solid waste management systems on human health and environment could be considerable in Gaza Strip.

4. Environmental and Social Concerns:

Environmental regulation and promotion of the efficient use of infrastructure projects help reduce adverse consequences from existing infrastructure. More options are available with new projects, although investment decisions can be consistent with environmental objectives only if environmental impacts are identified and assessed. Experience with environmental assessments in Gaza Strip demonstrates that construction projects are least likely to impose stress on the environment if such assessments occur early and influence the design of individual projects.

As the scale of construction projects grows, environmental consequences became increasingly significant. Environmental assessments should take a broad perspective capable of recognizing regional effects and induced economic impacts, as well as the potential consequences of broad economic conditions for the project. Moreover, even though large investment programs may be broken down into sub-components and implemented in sequence, it is usually necessary to conduct the environmental assessment on the basis of the overall program (11).

Environment friendly building and construction are essential for improving living standards and offering public health protection. With sufficient care, providing the infrastructure in Gaza necessary for growth and poverty reduction can be consistent with concern for natural resources and the global environment. Well - designed and - managed infrastructure can promote the environmental sustainability of human settlements. The relationship between infrastructure sectors (water, power, transport, sanitation) and the environment is complex. The most positive impacts of infrastructure on the environment concern the removal and disposal of liquid and solid wastes. But much depends on how disposal facilities are planned and executed (12).

The fact that environmental damage hurts people, both today and in the future, provides additional grounds for rethinking our measurement of progress. Indeed it raises special concerns, for unlike education, health, nutrition, and life expectancy, which tend to be improved by economic growth, the environment is sometimes damaged by that growth. Furthermore, the people suffering from the damage may be different from those enjoying the benefits of growth. They may be today's poor, or they may be future generations who inherit a degraded environment. For these reasons it is essential to assess the costs to human welfare of environmental damage and to take account of the distributional impacts of policies (13).

Sustainable development is development that lasts. It has been argued that the adverse impact of economic growth on environmental degradation can be greatly reduced. Poor management of natural resources is already constraining development in the Gaza Strip, and the growing scale of economic activities will pose serious challenges for environmental management. But rising incomes combined with sound environmental policies and institutions can form the basis for tackling both environmental and development problems. The key to growing sustainability is not to produce less but to produce differently. Uncertainty is an inherent part of environmental problems. To reduce it, decision makers need better information about environmental processes and social preferences (14).

5. The Impact of Construction on the Environment:

Construction operations and products have an impact on the environment in - several directions, these are:

- Resource deterioration, e.g. dereliction of land from quarrying and extraction of sand, clay and limestone, use of energy in the production of materials.
- Physical disruption, e.g. soil erosion, silting of reservoirs, disruption of ecosystems, climatic changes, noise pollution.
- Chemical pollution, e.g. particles released in the production and transportation of materials, pollutants produced in manufacture of some building materials.
- Social disruption, e.g. dislocation of inhabitants of the sites of roads.
- Undesirable residual impact on the environment from temporary structures, uncompleted buildings and untidy sites.

Some materials, such as asbestos, could be harmful to the labors handling them, and occupants of buildings. Of the constituents of paints, first lead, and more recently, benzene and formaldehyde, have turned out to be hazard (15). Moreover, building services and insulation materials account for about 50% of all global chlorofluorocarbon consumption (16). Great amounts of energy are also used in the production of materials such as bricks, plastics and paints. The single largest and product of the construction industry, buildings, greatly affect the environment since they use around two - thirds of all energy used. In addition, the construction of new buildings accounts for around 5% of total energy consumption during their production processes. Buildings in use and the construction of buildings consume vast quantities of natural resources and are responsible most significantly for many undesirable environmental effects.

An unfortunate consequence of construction industry is the prevalence of developers who favor the use of new green field sites in the Gaza Strip. Whilst this is understandable in the context of ease of development and cost effectiveness, the effect upon the environment is simply one of leaving existing buildings, structures and sites in derelict and ruinous condition. Land use has also a great environmental effect on construction industry. There is no doubt that habitat destruction lies at the root of much vehement public condemnation of construction.

Environmental effects from construction industry can result from inappropriate construction site practices that discharge pollutants, e.g. oil waste into water courses or through contaminants that go into land which feed into natural water resources. Waste emanating from construction industry is a major problem leading to detrimental environmental effects. Around 11% of all waste in the Gaza Strip results from construction demolition which is deposited in land - fill dumps or just dumped on the streets.

Environmental effects of construction result in a number of comfort disturbances to individuals living and working the environs surrounding any construction project. These are included: noise of construction equipment, dust from operations and traffic, nuisance from temporary dwelling and construction traffic, and hazardous contamination from toxic wastes.

The end products of buildings do give rise to environmental effects through the need for water and sewage treatment plants, water supply and storage facilities and the environmental effects associated with supplying and maintaining water resources to new and developing infrastructures. These lead to the knock - on effects of development.

6. Looking Ahead:

Gaza Strip is one of the areas of the region which is expected to undergo considerable economic development in the coming years. In planning a strategy towards the protection of environment and sustainable development, Palestinian are faced with many of the same issues confronting other developing nations. Foremost among these are population growth and adequate water supply and sanitation, both of which are quite critical. In Gaza Strip, as in other developing countries, there is a considerable lack of environmental public awareness about the interrelated nature of all human activities and their effects on the environment. This is due to lack of education, inaccurate or insufficient information and in some cases disinterest because of severe poverty and inhuman living conditions.

The environmental effects from construction industry have to be tackled on different levels: political, economic and educational. These three variables are independent. Without theoretical and practical knowledge, people will never achieve environmental and ethical awareness, values and attitudes. Skills and behavior should be consistent with sustainable development and necessary for effective public participation in decision making.

While basic education provides the underpinning for any environmental and developmental education, public awareness raising and training should be incorporated as an essential part of learning. It should have a job - specific focus, aimed at filling gaps in knowledge and skills that will help individuals to find employment. At the same time, training programs should promote a greater awareness of environment and development as a two - way learning process. The need for raising public awareness and for training is also strongly emphasized in Agenda 21, UNCED and the Declaration and Recommendation of Tbilisi Intergovernmental Conference on Environmental Education (UNESCO and UNEP 1977).

Palestine should follow a program to promote sustainable development through the building of better institutions, and providing appropriate information, investment, and incentives. The current and proposed projects have both positive and negative environmental impacts. It necessary, therefore, to assess the impacts of the projects and to take certain measures to mitigate the negative impacts. An action plan for the future should establish program priorities and goals over the long - term, and delineate a framework for policy, planning and research based on collaborative efforts of international and local agencies as well as universities.

As Gaza Strip has scant economic resources, it is recommended to examine the potential for the reuse or recycling of construction materials. The Production of construction derbies should be minimized so that only waste of the best quality possible, which has good recycle or erase possibilities may remain. Environmental impact assessment should be taken into consideration on every construction project. Further studies to analyze the impact of construction materials and construction derbies on the environment are required.

7. References:

1- Pearce, D., 1991, A sustainable world: who cares who pays? Vol. CXXXIX, No. 5420,493 - 505.

2- Croome, D., 1993, Environmental concerns for the construction industry, Proceedings of the international symposium CIB W - 65, Trinidad.

3- Ofori, G., 1993, Construction and the environment in developing countries, Proceedings of the international symposium CIB w - 65, Trinidad.

4- Mukhallalati, L., M. Ajjour, M. Gischler and R. Koopmans, 1995, Water scarcity and quality deterioration in Gaza, Proceedings of MEDCOAST 95 conference, Tarrangona, Spain.

5- EPD/DURP, 1995, Emergency resources protection plan for the Gaza governorate, Ministry of Panning and International Cooperation

6- Lyonnaise des Eaux, 1995, Assessment of water and sewage public services in the Gaza Strip.

7- Enshassi, A., 1994, The relationship between development and environment in Gaza Strip, paper presented in water quality seminar in Jerusalem.

8- UNCIAD, 1993, Prospects for sustainable development of the Palestinian economy in the West Bank and Gaza Strip, United Nations, Geneva.

9- Commission of the European Communities, 1993, Formulation of Gaza City solid waste disposal, project, Agro vision. Holand, bv.

10- Guarada, R., 1993, Infrastructure services for the Palestinian people, Shu'un Tanmawiyyah, Arab Thought Forum, Jerusalem.

11- Bartone, C. R., et al, 1994, Toward environmental strategies for cities: policy considerations for urban environmental management in developing countries, Discussion paper 18. UNDP / UNCHS / World Bank urban management program, Washington, D. C.

12- Enshassi, A., 1995, Political changes and the new development in Palestine, paper presented at the 19th international conference INTA, Wien, Austria.

13- Anderson, R. et al, 1990, The use of economic incentive Mechanisms in environmental management, Research paper 5 1, American Petroleum Institute, Washington, D. C.

14- Koch - Weser, C., 1994, Securing environmentally sustainable development in the Arab Countries, Speech delivered by the council of Arab Ministers responsible for the environment. World Bank, Cairo, Egypt.

15- Jackson, J. A., 1990, Choosing paint systems, The Canadian Architect, May, pp. 49 - 50.

16- Curwell, S., 1990 Greenprint for the future : environmental design, Architects Journal, 12, December, pp. 45 - 48.

Managing construction projects within emerging information driven business environments

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Abstract
In a growing globalised economy characterised by volatility and intense competition, organisations that continue to be successful are the ones that learn to adapt their systems of working to dynamic change. This requires speed as well as quality, and can be addressed through greater organisation flexibility and responsiveness. Collaborative approaches to business provide one way of attaining such flexibility by construction companies. This is significantly influenced by how companies acquire, use, store, re-use and integrate relevant information into their operating systems. The impact of information and its associated technologies on communications within construction has been considerable, albeit at a slow rate of growth. Traditionally, the construction process has been dominated at all the various key stages by the communication of information between individuals or organisations in graphic, textual, and/or verbal formats. There is substantial potential for integrated IT options to positively influence the efficiency of these information flows. As construction organisations explore more collaborative approaches to business, it will become essential to address the way information is utilised by industry for its future markets. This paper presents recent developments in communications and information technology that will have significant impact on the management of the production processes in construction. It discusses the implications of these evolving technologies and highlights the likely changes to both construction organisations and construction processes over the next decade.
Keywords: Information, Construction, Processes, Organisation

1 Introduction

The global market for construction is characterised by change: changes in technology; changes in procurement routes; and changes in finance, are all influencing the industry, its constituent organisations and project operation. Coupled to this, the increasing demands by clients for greater cost-efficiency, assured quality, and shorter time scales have led construction organisations to seek new management approaches to remain competitive. The increased use of Information and Communication Technologies (ICT) is central to most if not all these approaches. This paper examines some of the underlying factors that have contributed to the current evolving developments in the use of information and its technologies in construction. It also presents some of the recent developments in communications and information technology that will have significant impact on the management of the production processes in construction. It discusses the implications of these evolving technologies and highlights the likely changes to both construction organisations and construction processes over the next decade.

2 Construction and IT

The effective management of information resources within construction impacts both the success of projects and overall performance of individual construction companies. The introduction of IT and communications technology within construction to improve the management of such information resources has progressed through three phases. The first phase lasted up to the late 1970s. This entailed use of IT to achieve efficiency and cost savings in the processing of information. Improvements in this phase did not alter the way in which the information was organised but rather attempted a speed up of the manual processes. Many systems developed were directed at the operational level and found use in secondary activities, such as word processing and bookkeeping, to support the management of construction companies and projects. The second generation of IT developed for the construction industry evolved during the late 1970s and continued through the late 1980s. The primary aim for most of the developments in this era was to have the IT function aligned with, or supporting the functions of a construction company. The development of various application systems to tackle time-consuming or iterative operations took place within this period. The main achievement of this phase was isolated automation of tasks in the design and construction process (Anumba et al., 1997). These included stand-alone systems for project planning, estimating, and accounting and financial reporting. According to Emery (1990), many of the strategic benefits from IT systems in this period proved to be less sustainable than originally predicted. Many construction organisations emerged from this era with large IT cost structures and also doubtful opinions of IT by senior management (Cross et al., 1997; Violino, 1997). The third generation of IT dates from early 1990s, and is still evolving. This is addressing the integration of the stand-alone systems developed in the second phase, in order to maximise the use of IT as a strategic resource for construction. It also focuses on the use of IT as a communication medium capable of establishing and maintaining favourable supply chain relationships. The developments for construction have almost exclusively taken advantage of innovations achieved in other domains, and as such have moved at a pace behind IT leaders.

3 The driving factors

Several factors have contributed to the emerging development in the use of IT. within construction. Not too long ago, the term IT meant putting a computer on every worker's desk -i.e. computerisation (Wong, 1996). There is evidence that the emphasis is switching from computerisation to business enhancement. Thus there is greater concentration on automating the processes of the project and the construction organisation. The project management function is based on the timely delivery and documentation of construction information. The delivery of construction information has traditionally been dominated by paper documents like blueprints and specifications (Laflin, 1997). These take the form of graphic, textual, or verbal information formats exchanged between project team-members. Typical information components include drawings, specifications, change directives, estimates, management logs, and field reports (Tenah, 1986). Because all members of a project team share these information components, the exchange of construction information is seen as one of the critical tasks in the construction management process (Miah et al., 1998). In today's highly competitive world, meeting the need to compress project lead times and to achieve cost optimisation is vital. At the same time, the growing involvement of construction organisations in multi-partner projects is increasing the complexity of managing projects. For any construction enterprise involved in the running of such large and complex projects, being able to handle the volume of documentation more efficiently can have a major impact on reducing project time scales and costs. The potential for such cost and time savings exist in the form of integrated information technologies (Cross et al., 1997).

3.1 IT factors

The main benefits of the change brought about by IT are speed and *virtual proximity* two critical elements essential for achieving success in managing construction projects. Large volumes of data can be processed faster, and distributed to disperse geographical locations much quicker (Miah et al., 1998). This creates a virtual proximity for distant geographical locations. These benefits have been widely shared by both industry and the general society because of the falling cost for computers, an explosion in software development, and cheaper telecommunication costs.

3.1.1 Hardware and software revolution

While construction computing was once the domain of large, well-capitalised construction firms, the diminishing cost of personal computers has put computing power within the reach of even the smallest contractors. At the same time, rapidly developing hardware performance, coupled with the development of ROM storage drives, modems, scanners, and back up devices have added much needed functionality to personal computing. The evolution of connectivity hardware such as servers, network cards, modems and routers have linked computers together providing a forum for community collaboration. Construction software industry has matured as well. The rapid development of the Internet has also levelled the software playing field through the use of simple "open architectures" like TCP/ IP and HTML (Hypertext mark-up language). For example, the newest versions of the CAD programs Autocad, and Micro-station include features that allow multiple users to post, view, redline and collaborate through the use of an internet based web browser.

3.1.2 Lower cost of communication
High telecommunication tariffs have long been a major stumbling block for exploiting technologies that rely on electronic communication (ESPRIT, 1997). However, the implementation of the package of telecommunication liberalisation measures is already leading to lower prices and to more flexible pricing schemes. The WTO Agreement on Basic Telecommunication will contribute directly to the emergence of a global marketplace in electronic commerce. Similarly, recent international agreements to eliminate tariff (ITA) and non tariff barriers should rapidly bring down the cost of key Information Technology products, encourage the take up of electronic commerce and reinforce competitiveness.

3.2 The economic imperative

3.2.1 Hyper competition
For the construction industry, these business changes are reflected in diminished project schedules, increased global competition, and limited profit margins. The increasing cost of capital and shortened life cycle of business products has put added pressure on construction firms to reduce project schedules, increase quality, and reduce cost (Kubal, 1995). At the same time, the recent consolidation of several large construction firms shows that there is increasing global competition for construction services. Today, these changes are forcing many construction firms to analyse their business processes in an effort to do things faster, better, and cheaper.

3.2.2 Changing financing arrangement
Given the dynamic conditions of the global marketplace, owners are now demanding reduced schedules, and increased flexibility between members of the design and construction team. Increasingly contractors are moving to flexible design-build contracts and project partnering agreements in an effort to meet the demands of the rapidly changing marketplace. In the US clients are now expecting contractors to provide turnkey projects, which include services that range from financing to facility management. While developments have not progressed at the same pace in Europe, the on-going harmonisation of the single market is likely to impact heavily on financing mechanisms for construction projects.

3.2.3 Globalisation
Globalisation is the consequence of political and economic developments in the latter part of the twentieth century, whereby worldwide resources are employed to increase the gap between costs and turnover. This has in recent times been facilitated by the availability of technology and regulatory frameworks put in place by the WTO. The effect of globalisation is increased competition, as markets open up to worldwide competition.

4 Emerging trends

Current developments in IT for construction have progressed along four main line, standardisation (examples include the use of ED1 and bar coding), visualisation (comprising CAD, VR, and Augmented Reality), communication (including video/data conferencing, Intranets), and integration (employing infobases and project specific databases). The impact of these developments is leading to a new agenda for the construction industry.

4.1 New links for business

In recent years, both academia and industry practitioners have suggested that the way companies organise themselves, do business, and undertake projects is inherently flawed (Cross et al., 1997). As a result, traditional models of hierarchy, standardised procedures, functions, responsibility centres and performance measures for both the construction companies and projects have all come under scrutiny. So nothing short of organisational transformation has been advocated. Contemporary corporate activity such as downsizing, out-sourcing, de-layering, and re-engineering have found frequent use in the management of both the company and projects within construction. The resulting lean organisations have to rely on greater collaboration to achieve project and corporate goals, and have given rise to a growing trend in partnering. This affects the length of the communication chain for both project and company, as several parties become privy to decision-making, which hitherto had been the sole responsibility of one organisation.

4.2 Internets and Intranets

The Internet has a huge potential as it relates to construction. This is an industry that continually moves information back and forth between offices and remote job sites. Given the simplicity of web browsers, and a new generation of Internet ready software, many corporations are now using the Internet to publish and transfer information within a company or to members of a project team. This includes access to a wide range of construction documents, including drawings, specifications, requests for information, budgets and meeting minutes (Vanier et al., 1995). Currently, several construction and design firms are using Intranets to form project specific web sites (ENR, 1996). These new information technologies may help construction and design firms re-engineer the way they communicate on increasingly complex projects. The use of project specific web sites can be employed to save time and shipping costs as well as improving communication between isolated members of the project team (Novitiski, 1997). Authoring tools like Java or Active X provide potential for creating custom web centred applications that are geared specifically towards the clients' needs (Thompson, 1997).

4.3 Electronic commerce and virtual business

Electronic commerce is about doing business electronically. It is based on the electronic processing and transmission of data, including text, sound and video. It encompasses many diverse activities including electronic trading of goods and services, on-line delivery of digital content, electronic fund transfers, electronic share trading, collaborative design and engineering, on-line sourcing, public procurement, direct consumer marketing and after-sales service. It involves both products (e.g., technical goods such as material components in construction) and services (e.g. information services, financial and legal services); traditional activities (e.g. healthcare, education) and new activities (e.g. virtual malls). It is estimated that electronic commerce revenues on the Internet may increase to ECU200 billion world-wide by the year 2000 (Council for Economic Co-operation, 1997). This revolutionary growth will lead to profound structural changes in construction. Electronic commerce is not a new phenomenon. But there is now accelerated expansion and radical changes, driven by the exponential growth of the Internet (Faucheux, 1997). This involves transactions on a global scale between an ever-increasing number of participants, corporate and individual, known and unknown, on global open networks such as Internet (Hardwick and Bolton, 1997). Electronic commerce, of course, is not limited to the Internet. It includes a wide number of applications in the narrow-band (videotex), broadcast (tele shopping), and off-line environment (catalogue sales on CD-ROM), as well as proprietary corporate networks (banking). Also, the Internet is generating many innovative hybrid forms of electronic commerce - combining, for example, digital television infomercials with Internet response mechanisms (for immediate ordering), CD-ROM catalogues with Internet connections (for content or price updates), and commercial Web sites with local CD-ROM extensions (for memory-intensive multimedia demonstrations).

4.4 Digitisation of Construction Data

According to Negroponte, we are rapidly moving from a world dominated by atoms to one dominated by bytes (Negroponte, 1995). In the past design and construction relied on paper based documents to exchange information. Developments in information technology are changing the way that construction teams generate, store, transmit, and co-ordinate information (Basu, 1996). Over the past decade, many design firms have moved toward digital production of construction documents (bytes). Today, most design and engineering work is completed using computer aided design (CAD) software, and this is slowly replacing traditional paper based construction drawings. Traditional text based documents are taking on a digital form as well. Specifications, transmittal letters, memorandums, and other text based construction documents are increasingly produced using word processing software or spreadsheet programs.

4.4.1 Video conferencing

Rapidly developing video conferencing tools are also changing the way the construction projects are run. Virtual conferencing tools like CU-SeeMe, Microsoft’s Net Meeting and Netscape’s Collabra are now being bundled with standard computer software packages, and these tools will enable project teams to collaborate, redline drawings and solve problems without having to travel to the job site. These advancements will help reduce travel costs and improve project communications.

4.4.2 Infobases

Increasingly, construction manufacturers are using the Internet to publish information regarding their product lines. Traditional paper based brochures, catalogues, and specifications were cumbersome to use, take up room, and information goes out of date quickly. Digital catalogues are now being posted to a manufacturers web site where specifications and pricing can be updated regularly. Currently, several web sites provide access to manufacturers data including, FM Link, Construction Net, Canadian Engineering Network, Building On Line and others. There are other projects under development to ensure effective exploitation of these technologies for the engineering sector. For example, the GENIAL project under the Global Engineering Network Initiative is an ESPRIT. programme aimed at developing Intelligent Access Libraries to meet the particular needs of the engineering sector within the EU (Radeke, 1997).

5 Scenarios of the future

Soderberg (1996) in a view of the future construction process presented three scenarios of working within the industry from the design, production, and the property management stages. While these scenarios incorporate various applications of IT and communications technology, they still present the industry from a functional perspective. According to Mowshowwitz (1997) and Xian-Zhong and Kaye (1997), there is ample evidence that the future of industry will not be driven by this functional approach.

5.1 Business of construction

Electronic commerce is an emerging market. In this fast moving and highly fluid environment, we are seeing the development of a wide array of innovative virtual businesses, markets and trading communities. Companies are now routinely outsourcing over the Internet functions such as order fulfilment to specialist firms. Materials suppliers and distributors are "going virtual", outsourcing the physical warehousing and movement of goods to logistics specialists. Buyers, sellers and intermediaries are forming industry-specific Internet markets in such diverse fields as real estate and construction equipment. Similarly, global construction and engineering industries, such as automobile, computers and aerospace, are actively integrating their supply chains through the Internet. New functions are now being created. Innovative virtual middlemen are providing value-added services- such as brokering, search and referral- to businesses and consumers.

5.2 Winners and losers

These emerging trends will result in an industry with organisations with little direct semblance to the present state of construction. The industry will witness some *winners* and losers as it goes through this structural change. Traditional professional disciplines that give rise to the industry's functional oriented structure will be replaced by more flexible systems, in which knowledge and capability will be widely available through global infobases. This will give rise to the loss of some job functions, and naturally result in the creation of new ones. Although the traditional functions will still be relevant, individuals will have to combine capabilities beyond the boundaries of existing professions and become what the British Computer Society has termed *hybrid managers.* Many lower-level management and clerical positions will be displaced, as work designs, work flow, reporting systems, accounting and control mechanisms are automated through the availability of IT Equally, many construction organisations will have to do business in different ways from today. New forms of *individual to individual* commerce are appearing.

6 Potential impact on construction

6.1 Organisation

The availability of current technology will enable both individuals and construction companies to form *virtual organisations.* This will help to overcome the problems of physical interaction between the various parties of the construction project, and facilitate the requirements of speed and virtual proximity. The management of projects and organisations will experience more electronic and less paper-based information particularly in the areas of specifications and regulatory instruments. There will be a move towards smaller organisational units, virtual teamwork, and a growth in tele working. In such virtual environments, team members will seldom share a common workplace, and in some cases may rarely see each other.

6.2 Project

The prevailing market forces and recent developing trends are placing new demands on the management of projects within construction. The effect is a growing awareness regarding quality, productivity, which are pushing for fundamental changes in the way projects are managed. These demands are reflected in developments such as partnering, concurrent construction (Anumba et al., 1997), total construction (ECI, 1994) and electronic management of project documentation (Polaine, 1997). The main issue that will be addressed at this level is greater integration of the construction process. Such integration will address various issues including the electronic distribution of all project documentation to allow instant access to information, and the networking of project teams.

6.3 On-site operations

Future developments in areas such as speech recognition and wearable computers may also help streamline the usability issue. Faster processors in low-cost computers and advances in programming techniques have made *automatic speech recognition* (ASR) a major focus of software developers. Currently, products like Dragon Systems allow users to dictate correspondence to their computers, and in the near future construction users may become less dependent on the keyboard as an input device. Similarly, low cost user-friendly wearable computers are now becoming available. The co-ordination of projects from remote offices will incorporate more real-time visual links. Also, electronic archiving for progress reporting at the site will find increasing application within construction. Preliminary developments in this direction have been achieved by Gaugh et al. (1997), with the development of the Vision Digital Library. The use of global-nets such as GENIAL for access to material specifications and construction detailing both at the design and construction phase will significantly impact the process and culture of construction.

7 Issues requiring attention

While these advances are changing the way that construction companies work, there are still some concerns regarding the wide scale implementation of information technologies. Some prominent issues include usability, legal issues, and training requirements.

Part of the appeal of the World Wide Web has been the user friendliness of the web browser. Because these browsers use a simple point-and-click interface, users can be trained in their use in a matter of minutes. Similarly, e-mail systems, the modern equivalent of the telegram, also provide users with a simple method of exchanging information and electronic files. In essence, the best IT tools are like FAX machines: products that are simple to use, require little training, and can be put to work immediately.

Generally the contract process dictates that information will be processed in linear fashion between legally responsible parties. As such, a typical document might flow from vendor to subcontractor, from subcontractor to general contractor, from general contractor to architect, from architect to engineer and back again. Evolving IT applications like the project specific web site, streamline information transfer by placing information at a central hub where all parties can access it. Unfortunately, this transfer circumvents the traditional chain of command, and many contractors have concerns regarding contractual liability and professional property issues.

A final concern is training the work force to stay abreast of the rapid evolution of the electronic age. While other industries have embraced the use of information technologies with dramatic production improvements, the construction industry has been slow to exploit the new developments in information technology. With an under-educated work force and low operating margins, construction firms have been reluctant to make major investments in IT. At the same time, the tidal wave of electronic change has created a paralysing situation where construction users are waiting to get a clearer understanding of the paybacks associated with their information technology investments. Recent research shows that training accounts for 55% of the total ownership investment in a business desktop computer (Park, 1997). Given the trend toward faster project schedules, global collaboration, many sophisticated contractors are now implementing some of the technologies discussed herein. Increasingly, architects, engineers, and contractors will have to make a substantial investment in employee training to realise the productivity improvements that are inherent in IT.

8 Conclusion

Developments such as market shifts and globalisations is driving construction in new directions. The increased competition resulting from such open markets is being accentuated by client demands for more effective use of their limited resources. Technology can hold the key to achieving the level of efficiency required in such evolving construction business environments. The impact of technology is bringing about a new shape to the way construction utilises and manages the information resources that are employed in its processes. The nature of the industry's processes both at the project and corporate level will be driven by these emerging information and communications technologies. This will influence not only technology aspects of construction, but also alter the present functional structures within which the industry operates. In particular, the evolution of the Internet will facilitate the establishment of electronic commerce in the construction industry. Electronic commerce offers enormous opportunities for the construction industry. It will have considerable impact on the structure and operations of the labour market Construction will need to adapt to exploit these opportunities, expand existing businesses and launch new ones. Further analysis is needed to fully assess these changes but it is likely that new employment potential will principally be in information-based, high-value services. Training and education for these new skills will be needed. The organisations that can adopt and capitalise on these changes will emerge as leaders in the global market for construction.

References

Anumba, C.J., Baron, G. and Evbuomwan, N.F.O., 1997. Communications issues in concurrent life-cycle design in construction. BT *Technology Journal,* **15**(1), pp. 209-2 16.

Basu, A., 1996. Impact of Information Technology on Construction Project Management. *Transactions: American Association of Cost Engineers.*

Council for Economic Co-operation, 1997. A global market place for SME's. *G7 Pilot Project.* Available: http://www.ispo.cec.be/ecommerce/g7.htm.

Cross, J., Earl, M.J. and Sampler, J.L., 1997. Transformation of the IT function at British Petroleum. *MIS Quarterly,* **21**(4), **pp. 40 l-420.**

ECI, 1994. *Total Productivity Management: Guidelines for the Construction Phase,* TF008/2/v1.

Emery, J.C., 1990. Misconceptions about strategic information systems. *MIS Quarterly,* **14**(2), pp. vii-viii.

ENR, 1996. Using the Web to Manage a Job. *Engineering* News *Record,* June 24, pp. 17.

ESPRIT, 1997. A European initiative in electronic commerce. *Communication to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions,* COM(97)157, Available: http://www.cordis.lu/esprit/src/ecomcom.htm.

Faucheux, C., 1997. How the virtual organisation is transforming management science. *Communications of the ACM,* **40**(9), pp. 50-55.

Gaugh, S., Wei, L.I. and Gaugh, J. 1997. The VISION digital video library. *Information Processing and Management,* **33**(4), *pp.* 413-426.

Hardwick, M. and Bolton, R., 1997. The industrial virtual enterprise. *Communications of the ACM,* **40**(9), pp. 59-50.

Kubal, M.T., 1995. Upside-down contracting *Construction Business Review.* January/February 1995.

Laflin, J., 1997. Moving towards the paperless office: business options and costs. *Information Management and Technology,* **30**(4), *pp.* 169- 17 1.

Miah, T., Carter, C., Thorpe, A., Baldwin, A. and Ashby, S., 1998. Wearable computers: applications of BT's mobile video system for the construction industry. *BT Technology Journal,* **17**(1), pp. .

Mowshowwitz, A., 1997. Virtual organisation. *Communications of the ACM,* **40**(9), pp. 30-37.

Negroponte, *N.,* 1995. *Being Digital,* NY: Harcourt Brace.

Novitiski, B.J., 1997. New Net-Flavors: Technology Growing Faster than Vocabulary. *AEC Systems Magazine.* Summer 1997.

Park, A., 1997. New Machines Stirring Office PC Market. *Raleigh* News *and Observer,* September 22, 1997.

Polaine, I., 1997. PAFEC EDM site manager: reducing the document burden for construction site offices. *Information Management and Technology,* **30**(5), pp. 233-235.

Radeke, E., 1997. GENIAL - Turning engineering knowledge into an accessible corporate asset. In: Gausemeier, **J.,** ed *Proceedings, International Symposium on Global Engineering Networking,* Part II, April 22-24, 1997, Antwerp, Belgium, pp. 95- 104.

Soderberg, J., 1996. How can IT affect the construction process. In: Langford, D.A. and Retik, A., eds. *The Organisation and Management of Construction: Shaping Theory and Practice,* Volume 3, London: Spon, pp. 217-225.

Tenah, K.A., 1986. Construction personnel role and information needs. *Journal of Construction Engineering and Management* ASCE, **112**(1), pp. 33-48.

Thompson, J., 1997. Intranet project archival. *Construction Business Review,* **5**(5).

Vanier, D., Turk, Z., 1995. Internet opportunities for distributed construction information. *International Council for Building and Construction, Working group W78, Information Technology in Construction.* Available: http://delphi.kstr.lth.se/80/w78/html.

Violino, B., 1997. ROI- the most intangible benefits of technology are emerging as the most important of all. News *in Review,* CMP Media Inc., 30 June 1997. Available: http://techweb.cmp.com/iw/637/37iucov.htm.

Wong, A., 1996. The last 10 years: how did IT change your life? Available: http://www.geocities.com/Athens/5621/it.html.

Xian-Zhong, M.X. and Kaye, G.R., 1997. Beyond automation and control: manufacturing information systems from a strategic perspective. *International Journal of Information Management,* **17**(6), pp. 437-449.

Sustainable design construction and the performance concept

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Abstract:
"Interest, interactions and implementation of sustainable development in The Netherlands "

Sustainable development is a major politic issue in The Netherlands. The growing attention for sustainable design and construction is mirrored in governmental policy of public facilities as to create interest, promote interactions and make implementations happen towards a different, sustainable attitude in the entire building branch. The developments are to be reported in the biannual reports on a so-called "Sustainable Building Action Plan".
This presentation illustrates the process of gaining mutual interest in the demand and supply of real estate by implementing a policy of exemplary effects in the procurement of public facilities. Within this context the commitment of (public) principals is an important success factor.
Referring to CIB W60 the results of the application of the performance concept in this procurement program will be emphasized, as the method facilitates a comprehensive approach from project-initiation to delivery.
The impact of new instruments and communication tools in order to facilitate effective interaction between partners in the process of project-initiation and procurement will be highlighted as well as the lessons from project-monitoring in a DFL 1.8 billion (USD 1. Billion) design-build procurement program for public buildings, during 1992 -1997.
In connection to this a decision-support system of expressing environmental matters in financial terms will be presented by, Marcel Dewever, the Dutch Chief Inspector for Environmental Affairs and a calculation model for assessment will be presented by Dr. Michael Haas from the Dutch Institute for Building Biology and Ecology, (NIBE).

Keywords: sustainability, fitness for use, design-build, comprehensive approach, assessment models, performance concept, intellectual challenge, total quality management.

1. **Introduction**

Sustainable design and construction can not be pursued as an autonomous task. It is part of the more comprehensive context of sustainable development.

This brings the issue into national and international policies and as a consequence it touches with the tension between environment and economy. Economic growth and a reduction of the pressure on the environment is a dilemma at first sight but it can definitely be successfully combined through changes in production, prices, taxation and government policy.

The aim should be to generate economic growth combined with a reduction in the environmental pressure. It affects key aspects such as:

- Environmentally-friendly goods and services which meet the ever varied needs of consumers
- Sustainable commercial practice in all sectors
- Environmentally-efficient technology in products and production, in processes, in vehicle use, in using knowledge as a production factor
- Efficient use of space, spatial quality and investments in the infrastructure
- Sustainable pricing and taxation on labor.

On the move toward a sustainable economy the Dutch government recently issued a policy documentation on Environment and Economy. The document's key areas of focus are: industry and services, agriculture and rural areas, traffic, transport and infrastructure.

The Dutch policy document covers 3 packages of activities:

- Generic government policy
- Combined actions by industry and government designed to accelerate the projected process of changes
- Other actions to be implemented in various sectors

This policy document is subject to monitoring and annual evaluation as to ensure the desired effects on society and daily life. Within this context the issue of sustainable design and construction has become a major concern of the Government Building Agency GBA.

With regard to the implementation the Government Buildings Agency GBA (in Dutch the Rijksgebouwendienst) does act as a pioneer in the quest for sustainable buildings. As one of the largest principals for the design and construction of non-residential buildings the GBA uses it's roll as a market player by aiming its public procurement policy at sustainable design and construction.

2. Sustainable construction in The Netherlands

The Dutch government has set itself the goal of achieving significant advances in sustainable design and construction in The Netherlands. The “Plan of Action for Sustainable Building”, issued by the Minister and State Secretary of the Dutch Ministry of Housing, Spatial Planning and the Environment in Sept. 1995, contains incentives for hitting that target.
A four-track policy will be implemented in consultation with our partners in the design- and construction industry. One of the tracks provides for the promotion and creation of sustainable government buildings. Another track provides for stimulation of quality management and better cooperation/interactions by demanding for integral quality guarantees.

The Netherlands is a small and densely populated country with a population of 15 million inhabitants, which is the highest average population density in Europe (407 inhabitants per square kilometer) It’s economy depends on industry - particularly chemicals and metal processing - , intensive agriculture and horticulture and on the country’s geographical position at the heart of Europe’s transportation network. These factors have led to major pressures on the environment.
The Government Building Agency GBA is the housing agency for State Civil Services in The Netherlands. It takes care of a real estate portfolio of approximately 6.5 million square meters gross floor area, corresponding with a US $ 8.7 billion present value in terms of property-management.

3. Sustainable construction and the performance concept

During the nineties a US $ 1. billion design-build program is executed in behalf of the construction of new courthouses and tax-offices all over the country in The Netherlands. The characteristic of these design-build contracts is to offer the project owner a turnkey project wholly designed and executed for a budget, for a period of time and for performances determined at an early design phase. (Since public contracts are concerned, this was done by competitive tendering). This procedure relieves the client of the management of numerous contracts and interfaces which are often blurred and potential bones of contention. Meeting the expectations of public project owners it offers them control over the building components by allowing this client/ owner to concentrate on sustainability and fitness for (sustainable) use. The coordination right at the start of the design and execution provides conditions for an integrated approach and effective interaction and as such it ensures the optimization of different aspects. Taking advantage of his role as a public procurement market player the Dutch Government Building Agency GBA introduced the application of the Performance Concept in numerous design-build

contracts in order to enhance better cooperation and interaction between parties as to facilitate the integrated approach in the building market.
The major advantages expected by applying the Performance Concept were:

Focus on output instead of input.
The main issue is to deliver the desired performance rather than to prescribe how to achieve this. As a matter of fact the skills and know-how of the design-build process belong to the supply-side rather than to the client-side. Therefore it should be proper for both sides when the client focuses on output-performances rather than on input prescriptions.

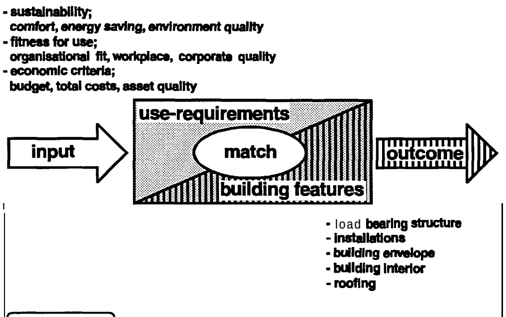
Focus on fitness for use instead of technical descriptions
For the client the building is a business asset, next to other business assets such as capital, staff, technology and information. The building is there to house the client's primary (business) process properly. Therefore the client should define his requirements in fitness for use criteria rather than in technical descriptions.

Stimulate the parties to invest knowledge and research as early as possible in the design process.
The design-build process always starts with a design-phase. The preliminary design phase is crucial, because this is where the comprehensive conditions for success in sustainability and fitness for use are determined. In the early preliminary stages of the design phase the potential on process-control is still large but the information level needed for process-control is poor. The design-build process carries on and more information will be provided but the potential on process control decreases. In order to provide the best conditions to achieve fitness-for-use performances within a reasonable budget frame more knowledge and research should be focused on upgrading the information quality in these preliminary design stages. (scheme 3).
Depending on the type of project the research can be focused on a data-bank of references (general projects) or research can be carried out on typology studies (unique projects).

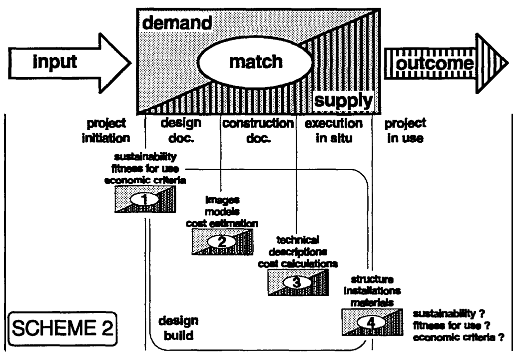
Take advantage of the private sector's efforts and creativity by allowing them to initiate an integrated design-build approach as early as possible in the design phase. The important success factor in achieving both sustainability and fitness for use is the integrated design-build approach from the very first design steps i.e. as early as possible in the design phase. Sustainability and fitness for use are both comprehensible issues that can not be treated successfully by the architect or whatever expert as a single professional. These issues need an integral approach that allows effective intellectual interaction within the fields of architectural design, building physics, construction and specific consultancies, providing environmental calculation methods, assessment-models and decision support systems. Such an approach facilitates the client in taking advantage of the supplier's efforts and creativity by allowing and stimulating them to initiate such an integrated design-build approach.

4. The problems of matching demand and supply

The design-build process can roughly be simplified by a black-box matching mechanism between the client's demand in use-requirements (fitness for use) and the tenderizer's supply in building features (scheme 1).This is not simple and there is a large risk for a mismatch at the moment of delivery.
Moreover this black-box process does in fact consist of partial demand/supply matching processes (phases), each characterized by their own "quality-language" So the mechanism of matching demand and supply in a performance based design-build contract is in the continuous process by transforming and interpreting quality criteria differently during the phases of the design-build process: (scheme 2).



SCHEME 1



SCHEME 2

- The initial phase provides the brief in terms of fitness-for-use performances and a budget-frame.
- The design-phase provides images, sketches and drawings, models, costs estimations, that should match the brief (match 1)
- The construction documents provide technical descriptions, drawings, cost-calculations, that should match the design (match 2)
- The execution phase provides materials, load bearing structures etc., that should match the construction documents (match 3).
- The phase of use provides the actual fitness for use of the building features, the infrastructure, the building envelope, i.e. the building as a whole, that should match the brief and should fit into the budget-frame (match 4)

Each phase introduces it’s own “quality-language” and it’s own risk for mismatches and at he moment of delivery it will therefore be difficult to match the integral outcome with the initial demand performance. In a design-build contract these black-box matching processes actually are of no interest to the user/client, who is mainly interested in the sustainability and fitness for use as an outcome. The tenderer is committed to deliver this outcome in a fit for use building within a fixed budget. But as a matter of fact the critical success factor to client satisfaction is in the continuous process of matching demand and supply over the phase, i.e. on allowing the client to “take a look into the black-box”.

This is where legal aspects show up as the agreement includes a fixed budget and a total quality output that the tenderer is committed to deliver. Any mutation caused by communication between client and tenderer during this process can alter the commitments and liabilities.

So the problem of matching demand and supply in a performance based design-build contract is in the continuous process of transforming and interpreting quality criteria differently during the phases over time. On the one hand the client should not be bothered by the complexity of these matching processes and in fact he is hardly interested in these. On the other hand the critical success factor of client satisfaction is determined by involving the client in these matching processes without mixing up liabilities.

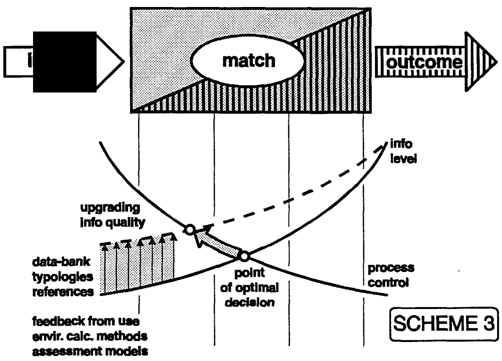
5. Monitoring the process

The matching of demand an supply appears to be a matter of keeping the initial performances on track while transforming and interpreting quality differently during the phases of the design-build process.

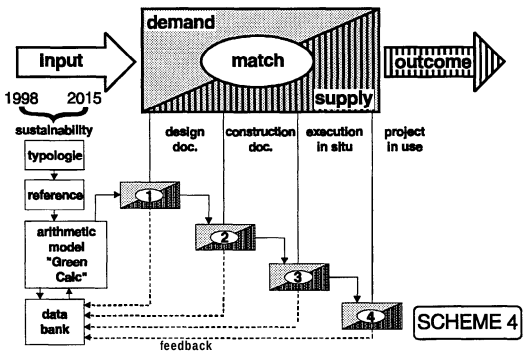
A proper way to complete this mission is by monitoring the entire process from project-initiation to delivery and by organizing communication with the client accordingly.

Referring to chapter 4 there are at least 4 moments of partial matching mechanisms involved in the design-build process.(scheme 4)

Process-control should focus on these moments as they introduce specific risks for an eventual mismatch between demand and supply.



SCHEME 3



SCHEME 4

The first moment of risk is when the performance-based brief is transformed into the conceptual design sketch. This is the first effort in creating a model of the entire integral building quality; it provides the result of an inevitable implicit interpretation of the total-performance desired by the client.
This is where the method of monitoring should be highly effective because it is yet an early stage of the process while investments are still low-profile, whereas the concepts potential for the desired total-performance is of strategic value in terms of output-control
The match is between:

- The demand in terms of sustainability, fitness for use, economic and organizational criteria, corporate identity, budget frame and:
- the supply in terms of the architectural design, potential for sustainable construction, spatial and functional performances and estimation of building costs.

In order to facilitate a proper way of matching knowledge, skills and tools are needed in behalf of decision support systems in this early phase of conceptual design.
Therefore research should be carried out on the basis of:

- a data bank providing information and references of previous projects based upon feedback from use, including maintenance and design-build experiences/skills
- typology studies providing knowledge and tools how to relate between sustainability, use-patterns and the potential design-concepts as to create best conditions for a successful match.
- environmental calculation methods in design and construction as performance concept.
- assessment models for monitoring fitness for use as well as sustainability during the design-build process.

The second moment of risk is when the design (demand in terms of images, potential for sustainable construction, spatial and functional performances and estimation of building costs) is to be matched by the construction documents (supply in terms of technical descriptions, drawings, administration and building costs calculations)
this is when the selected method of monitoring, once applied in the design phase, can easily proceed in interpreting the desired design quality into technical documents, relying on the existing expertise and the role of the architect in the traditional building process

The third moment of risk is when the execution takes place on the basis of the construction documents. Once the design is mirrored consistently in the construction documents, the quality procedures for safety, sustainability and execution in situ should cover most of the risks for mismatch at the moment of delivery.

Nevertheless attention should be paid to the relation between the performance of materials, the execution quality and the predictable sustainability and service life.

The fourth moment of risk is when delivery has taken place and the period of use starts. The after-care services do not cover the risks of a mismatch in terms of fitness for (sustainable) use.
Therefore the phenomenon of performance - guarantee- assurances becomes increasingly the trend in the real estate branch and subject for research as to protect the client from unexpected blows and liabilities.

As these moments include risks for a mismatch between demand and supply monitoring should provide -methods, models and skills that can cover these risks. In behalf of monitoring sustainable design and construction an advanced system of expressing environmental matters in financial terms will be presented by Marcel Dewever and Dr. Michael Haas.
Marcel Dewever is the Chief Inspector on Environmental Affairs with a special mission to empower the GBA-management by implementing sustainability in their decisions. For that purpose he developed a three-step arithmetical model in cooperation with Michael Haas for quantifying the environmental effects of buildings (“The TWIN-model, an environmental calculation method as performance concept”) and for expressing these effects in financial terms.

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Collecting systems for waste return in the building industry: combining political, logistical, economical and environmental aspects

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The amount of building and demolition waste is a growing concern. Recycling techniques have been developed for many materials. However, the building and demolition waste must be returned from the building site to the recycling plant to have the waste recycled. A system for collection and return of waste must be available for this purpose.

For the development of such a system, a multi-disciplinary approach is necessary: political and logistical aspects have to be accounted for: optimisation can take place by economic and environmental analyses of several options for the system.

This contribution clarifies the use of the above mentioned disciplines for the development of a “return system”. Two cases are dealt with: TRESPA cladding panels and expanded polystyrene insulation material.

Keywords: building waste, economy, life cycle analysis (LCA), logistics, policy, returning system, TRESPA, EPS

1. Introduction

Since the Brundtlandt report ‘Our common future’ we know the word ‘sustainability’. Sustainable means that social and economical processes fit within the limits set by nature, now and in the future. Several countries have environmental policy plans nowadays aiming at a sustainable development.

In the Netherlands we have the National Environmental Policy Plans (NEPP1 1989, NEPP+ 1991, NEPP2 1993, NEPP3 1997), a product policy (‘Product and environment’, 1993) and a special policy on sustainable building (‘Sustainable building’ 1991, Plan of action Sustainable Building 1995, Plan of action Sustainable Building 1997). These policies have three main topics as a foundation:

- Integral chain management
- Energy extensivation
- Quality improvement.

Especially the first topic focuses on recycling: product chains have to be closed. This closing, however, must not shift environmental problems to other environmental compartments. This means that we have to analyse the environmental impacts in an integral way: analysing all stages in the chain and looking at all relevant environmental impacts.

Recycling in the building sector got a lot of attention in the past years. Building and demolition waste is one of the largest waste streams in the Netherlands (approximately 14 Mtons a year). In 1988 this waste stream was appointed as a priority. In 1993 the first Implementation Plan for building and demolition waste was published. In this Plan actions were mentioned aiming at a reduction of 5% reduction in growth of the waste stream and maximising the recycling (90% in 2000) and a minimisation of disposal and incineration (maximum 10% in 2000). A very important action was a legislative ban on disposal that was introduced in 1996: Nowadays it is not allowed to dispose waste that can be incinerated or recycled. Furthermore the costs for disposal and incineration are strongly increasing.

This Dutch attention for recycling is not unique in Europe. We all know that recycling is a hot topic in all European countries and in the EU policy.
But how do we collect the building and demolition waste? How do we return the waste to the place of recycling? Who is responsible for the collection? Many questions for the

producers of building materials who are more or less responsible for their materials wastes.

In this contribution I give two examples of producers who have answered these questions and have introduced a return system. You will find the following in this contribution:

- in chapter 2 you find an overview of return systems for building materials in the Netherlands
- in chapter 3 we explain the return system of TRESPA cladding panels
- in chapter 4 the case of EPS insulation material is described
- in chapter 5 we draw some conclusions about the introduction of return systems.

2. Return systems in the building industry

In the early nineties the first of many initiatives to return building and demolition waste to the original producers started. Some examples from the Netherlands are:

- Dutch Association of Plastic pipe Manufacturers (FKS) introduced in 1991 a return system for plastic pipes. The plastics are reused in two production sites for new three-layered sewerage pipes;
- The Association of Plastic Facade elements (VKG) also started early research. In 1997 a return system is introduced;
- Rockwool introduced big-bags for mineral wool building waste;
- For PVC-roofing and modified bituminous roofing options for returning and recycling exist;
- Producers of EPS-insulation material are looking for efficient ways of returning and recycling;
- Building Recycling Netherlands (BRN) takes initiatives to co-ordinate the collection of building materials;
- TRESPA introduced in 1996 it's return system for TRESPA cladding panels.

The return and recycling of stony materials has been very successful in the Netherlands (and also in other countries). Special containers for stony waste are obligatory placed on the building or demolition site and returned to the sorter and crusher. A special certification system is introduced (Korrelmix) to ascertain the quality of the aggregate. The introduction of such systems for the smaller waste streams is, however, much more difficult.

3. The return system of TRESPA cladding panels

TRESPA METEON is a large-size, flat panel based on thermo-setting resins homogeneously reinforced with wood-fibres and manufactured under high pressure and temperature. TRESPA METEON is used for outdoor applications in the building sector, for example as a cladding panel, for roof eaves, balconies, street furniture, etc.
TRESPA waste material is released at the production of the plates, during pre-fabrication of the plates (residual waste) to saw the plates on the sizes needed for the building (sawing losses) and during demolition.

In this chapter I explain a feasibility study of TRESPA International and the introduction of a return system. In paragraph 3.1 you will find a short introduction of TRESPA's motivation. In paragraph 3.2 the choice for a logistical feasible system is described, in paragraph 3.3 and 3.4 the environmental aspects and the economics are described and in paragraph 3.5 I explain the considerations and final introduction of the return system.

3.1 TRESPA and product responsibility

TRESPA is one of the pioneers in feeling responsible for the environmental aspects of her products. In the period 1992-1994 several LCA-studies have been carried out. In 1995 a feasibility study for a return system has been conducted and an implementation scheme was developed. Both studies were subsidised by the Dutch Research Program for the Reuse and Recycling of waste materials, the NOH, on behalf of the national government.
The feasibility study indicated that a return system for residual waste was feasible through the dealers network. From internal research and a small scale production pilot it was concluded that reuse of the returned waste in the production of new cladding panels was very well possible.

A return system for demolition waste was not feasible (see below) TRESPA decided to introduce in 1996 a return system for TRESPA residual waste in the Netherlands, Germany and Belgium. In 1997 this return system is extended. TRESPA also started production scale experiments for the recycling of returned TRESPA material in new cladding panels. For this purpose a new installation is built.
The implementation scheme is finished in 1997.

3.2 Logistics

In the feasibility study several options have been studied. After discussions with relevant parties, some options seemed not feasible. The feasible options have been worked out:

For saving wastes

I Return system by dealers

For demolition wastes

II Return system by demolisher

III Return system by sorter

IV Return system by demolisher and sorter (combined)

In the model II, III en IV three variations are possible:

- Variation 1: Returning material to TRESPA, identification by a certificate, material is recycled;
- Variation 2: External incineration
- Variation 3: Returning material to TRESPA, no certificate, incineration in TRESPA kiln

In table I the assessment of these models and variations on management control, influence and recycling is shown.

Table 1 Feasibility of the TRESPAs returns system according to management control, influence and recycling

	Management Control	Influence	Reycling
Model I	+ returning by dealers, limited number	+ via agreements with dealers	+
Model II	- numerous potential demolishers	numerous unorganised demolishers	small amounts per collector leads to long storage periods
Model III	+ small group of sorters	+ organised sorters	+ small group of qualified professional collectors of waste streams
Model IV	- numerous potential demolishers and sorters	0 partly organised, partly unorganised	+ large direct flows, residual by professional collectors
Variation 1	idem model II, III and IV	idem model II, III and IV	idem model II, III and IV
Variation 2	worse for all models, flow is invisible for TRESPA	worse for all models due, flow is invisible for TRESPA	irrelevant
Variation 3	idem for all models	idem for all models	irrelevant

Source: [NOH,1996]

Model I was assessed to be feasible.
Model III is the most feasible system for demolition waste, preferably in combination with variations 1 or 3.

Model I is introduced. Model III not yet since the amounts of demolition are still rather low for this young product. Moreover, the introduction of a certificate is not easy and returning waste for incineration means that international agreements have to be made with other laminate-producers.

Model I is introduced as follows: Together with the cladding panels so-called LIKO pallets are delivered for the collection of residual waste. The returning of the LIKO pallets is combined with a follow up delivery. Therefore no additional transport is needed for the return system. To prevent additional sorting out of the returned material the appliers receive special collection instructions together with other product handling information. These 'playing rules' are imbedded in the Quality System of TRESPA.

3.3 The environment

Within the scope of the feasibility study a life cycle analysis (LCA) is carried out to elaborate the environmental consequences of different scenarios to operate the return system. In Figure 3.1 you will find the environmental profiles of five scenarios.

No preference could be made between reuse and incineration with heat recovery. By reuse less waste is produced but incineration has a better score for the energy use. In comparison with disposal, both reuse and incineration are better off, or at least have equal environmental performances.

Compared to the pre-return system daily practice, the incineration of combustible building waste, incineration at TRESPA produces less emissions and waste
A critical parameter in the LCA is the transport distance. The turning point lies at approximately 750 km.

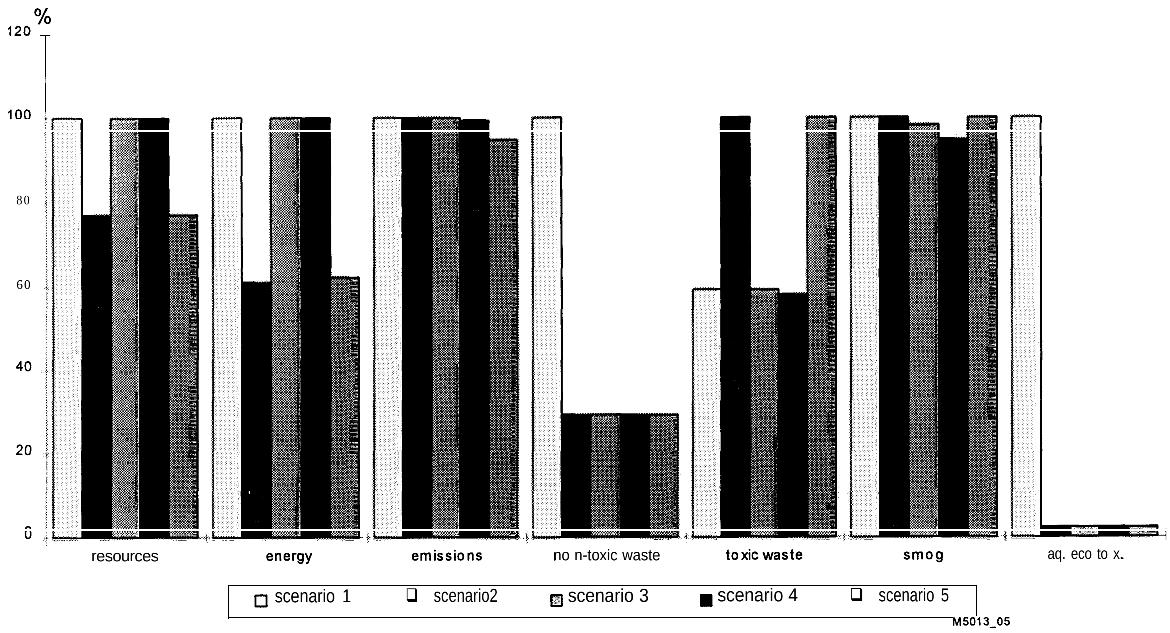

Figure 3.1 Five scenarios for the TRESPA return system: the environmental profiles

Scenario 1: reference situation: landfill after service life;
Scenario 2: thermorecycling at TRESPA;
Scenario 3: reuse in new cladding panels, 5% substitution of virgin material;
Scenario 4: reuse in new cladding panels, 10% substitution of virgin material;
Scenario 5: thermorecycling in a general incineration plant (AVI).
Source [NOH,1996]

3.4 Economics

The return system has three main costs: the investment and operation of the recycling installation, the use of LIKO pallets and the transport back to TRESPA. With the introduction of the return system no contribution was asked off the appliers. Since July 1997 TRESPA asks a contribution from the participating appliers to balance the costs of the return system.

In the feasibility study, the costs of the models have been estimated (table 2)

Table 2. Cost estimation of models

		1996	2005	2010	2015	2020
Model I	without variation	f 230,--	f 225,--	f 225,--	f 225,--	f 225,--
	variation 3	f 155,--	f 155,--	f 155,--	f 155,--	f 155,--
Model II	variation 1	irrelevant	f 275,--	f 235,--	f 230,--	f 225,--
	variation 2	irrelevant	f 230,--	f 230,--	f 230,--	f 230,--
	variation 3	irrelevant	f 205,--	f 165,--	f 160,--	f 155,--
Model III	variation 1	irrelevant	f 225,--	f 220,--	f 215,--	f 215,--
	variation 2	irrelevant	f 390,--	f 390,--	f 390,--	f 390,--
	variation 3	irrelevant	f 140,--	f 140,--	f 140,--	f 140,--
Model IV	variation 1	irrelevant	f 225,--	f 215,--	f 210,--	f 210,--
	variation 2	irrelevant	f 390,--	f 390,--	f 390,--	f 390,--
	variation 3	irrelevant	f 135,--	f 135,--	f 135,--	f 135,--

3.5 The return system of TRESPA

Based on the logistical, environmental and economical aspects, TRESPA has chosen to combine both ways of recycling in her return system: reuse, as it is technologically possible, together with an optimal recovery of the caloric value of the remaining returned material. Because of the importance of the transport distance the system is introduced in the Netherlands, Germany and Belgium.

4. The return system of EPS insulation

Expanded polystyrene (EPS) is a well-known insulation material in the building industry. It is applied in house-building, in office-building and in road construction.

Recycling of this material is feasible and results in environmental yields. Recycling of production waste is commonly carried out since years. However, the building and demolition waste is not returned to the producers but is collected with other materials and incinerated. The Association of EPS producers (Stybenex) therefore decided to carry out a feasibility study for a return system [2]. In this study, the logistics, economics and LCA of several routings are analysed.

This feasibility study showed that two routings are feasible to collect EPS waste material form the building site:

- a routing via the producers: they take the collected material back when they are delivering new EPS. Usually there is so much transport that this takes no more than 20-50 km. extra.
- a routing via sorters: EPS is collected in bags that are transported to the sorter on top of a container. The sorter serves as a depot.

These combined routings can close the EPS insulation chain for approximetaly. 80%. The feasibility of the routings will be tested in pilots in 1998.

References

1. NOH-report *9607, Retoursysteem voor TRESPA-bouwplaten, Een haalbaarheidsstudie (Retoursystem for TRESPA-panels, a feasibility study, in Dutch),* INTRON, 1996.
More information: TRESPA International, P.O. Box 110, 6000 AC Weert, The Netherlands, tel.nr. +31 495 45 83 58, fax.nr. +31 495 57 67 54.

2. NOH-report *9712, Gesloten kringloop van EPS uit bouwtoepassingen, (Closed loops of EPS form building applications, in Dutch),* INTRON, PI!MC, Stybenex, 1997.

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Managing Sustainability in Urban Planning Evaluation

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Abstract
Spatial planning evaluation has been recently reviewed as an activity characterised by a communicative-learning approach rather than a technical-rational one. This change has been given particularly emphases by the issue of sustainability, including ecological considerations, ethical aspects and the principle of public participation in urban planning.

In technical terms, an evaluation of urban sustainability needs an understanding of all the interdependencies between aspects and the effect that action in one aspect might have in others. Sustainability indicators should reflect these interdependencies in order to guide decision making toward the achievement of a sustainable urban development. However, current indicators which has been suggested at national and international level are quantitative in nature and specifically refers to the availability of specialist knowledge on some aspects. The elevation of these aspects and consequent imbalance and ignoring of others may result in unsustainable decisions in the long term and a less then sustainable environment.

An improvement in current decision making in the built environment, based on better communication and more effective negotiation between stakeholders on the actions to be taken, may lead to more sustainable decisions and the building of a common understanding of local sustainability. This requires clear information on urban environmental problems and robust communication channels between experts and citizens. They all need to be able to communicate at a sufficiently deep level and the earning of sustainability must be clear and agreed.

The paper investigates this problem, considering the lack of adequate infrastructures toward a common understanding of urban sustainability and illuminating the need to keep a systemic and pluralistic approach. It postulates a multi-modal thinking approach for establishing an integrated, meaningful and holistic framework for guiding the evaluation of urban sustainability in planning.
Keywords: multi-modal system thinking, planning evaluation, urban sustainability.

1 Introduction

An application of scientific logic in planning evaluation is usually adopted for clarifying consequences of different choices and planning options. It generally focuses on analysis, requiring a comparison of all the characteristics of various choice-possibilities in an explicit and systematic manner [1]. This means the separation of facts from values and basing experts judgement on quantitative indicators and on formalised methods for problem solving.

Traditional and 'formal' techniques, such as cost benefit analysis, assume to be able to assess the impacts of a policy proposal for all relevant variables of the proposal, in an empirical manner. The evaluation is understood as a demonstrative verification, which is based on formal rules of inference. Consequently, it addresses everyone who has the knowledge to understand the language used with the aim of stimulating an intellectual agreement.

This approach has raised a number of critical issues, such as the following: it does not include human values in the decisions, putting great emphasis on the known object and avoiding diversity, multiplicity and conflicts; it does not understand complexity, leading to a danger of reductionism in the analysis; it refers to an ideal public interest which is assumed as an external factor. A strong theoretical tradition has, therefore, emerged in recent years which views urban planning as a process of mediation between competing interests rather than the elusive pursuit of the public interest [2].

The new argumentative-communicative approach in planning evaluation reflects this shift from a comprehensive planning model to an incrementalist attitude in planning. The role of planning evaluation becomes to increase information and knowledge, improving public participation in environmental decision making. Evaluation is understood as a learning process which provides the factual basis of the issues for decision, focusing on language and on co-operation between parties [3].

One of the problems with this ideology in relation to urban sustainability is that no external reference point is acknowledged or even allowed, so there is no certainty that planning according to these wishes will in fact lead to sustainability in the longer term. In addition, when the wishes and views of different people or groups appear inconsistent there is no standard by which to arrive at consensus or to a final synthesis. Furthermore, it tends to ignore those who have no voice in the public arena with the danger that in practice those who shout loudest get heard. Therefore while less reductionist than approaches based on a comprehensive 'rational' model, there is still no guarantee of sustainability [4].

According to other authors [5] the fundamental question is 'how best to organise the form of discourse, to develop inclusionary argumentation and to build interrelations'. This calls for a framework which bring unity within diversity and an integrating mechanism or tool which can bring together the diversity of interests necessary to assess built and natural environmental impacts.

Urban sustainability is theoretically characterised as "a process of balancing and of synergetic integration (or co-evolution) between sub-systems, i.e. social, economic, physical (including the built heritage) and environmental" [6]. This process generally includes the conflicting requirements of sustaining the environment (environmental quality) and at the same time sustaining the flows of production and consumption necessary for the reproduction of the human species (quality of life) [7]. A common understanding of this concept should involve the consideration of a broad range of aspects both determinative (technical, based on empirical observations) and normative (non-technical, based on social values) which need to be simultaneously addressed in decision-making where problems are not always technically amenable to experts solution [8].

Following a multi-modal system thinking approach [9], the paper suggests a new methodological framework, a mechanism that brings unity within diversity with the aim to enlarge the actual network of social actors in decision-making, building an homogeneous vocabularv and a unique language of sustainable urban development.

2. Infrastructuring a common understanding on urban sustainability

2.1 The multi-modal system approach for integration of aspects

The multi-modal system thinking approach is based on the Cosmonomic Theory of Herman Dooyeweerd [10] who proposed a pluralist ontology, in which temporal reality has fifteen aspects (dimensions or level of information), as follows: Numerical, Spatial, Kinematics, Physical, Biological, Sensitive, Analytic, Historical, Lingual, Social, Economic, Aesthetic, Juridical, Ethical, Credal.

The modal aspects (each of which has a kernel meaning) are irreducible to each other. However, there are definite relationships between them, which allows an entity to function in a coherent rather than fragmented manner. These relationships are of three kinds.

1. *Dependency*. The laws of later aspects depend on and require those of earlier ones. Thus, biotic laws require those of physics, which require those of movement, etc.
2. *Functioning.* An individuality structure (entities and systems) functions in each aspect either as subject or obiect. This functioning individuality structure serves as an integration point for the aspects.
3. Analogy. Components of each aspect are mirrored, echoed in others. Such analogy is the basis for symbolic representation of knowledge on a computer [9]

Following this framework of laws, an integrated list of factors, functions and institutions which are relevant for the true long term sustainability of any built environment and its community has been developed from literature review and international reporting [11]. Table 1 illustrates this list of aspects, classifying them in accordance to the modal aspects and their core meanings.

This classification system is quite different from the traditional systems and it specifically refers to the *dependency* and the *functioning* relationships provided by the laws framework of modal aspects. It make the link between the modal aspects explicit, helping to understand how an action on one aspect needs to consider the laws of all the others, at different degree. For example, an improvement in the communication (acting in the lingual aspect) usually requires some historical processes for achieving an adequate level of technology to be employed and/or of creativity, and in less degree, all the other modal aspects from the analytical down to the numerical. This improvement may bring better social relationships and cohesion within the community, which in turn lead to a more sustainable leaving.

In other words, this framework does not tend to reduce the complexity of the problem, suggesting rigid ways for analysing urban sustainability. On the contrary, it forces you to think in an holistic and systemic manner, by integrating all aspects of reality, both determinative (empirical observations) and normative (social values).

Modal Aspects	Kernel Meaning	Examples of factors and institutions for urban sustainability
Numerical	Awareness of 'how much' of things	population, amount of various resources, number of species, accumulation
Spatial	Continuous extension	layout, shape, density, location, proximity, terrain shape
Kinematics	Movement	mobility, accessibility, wildlife movement, viability, transportation, roads, infrastructures
Physical	Energy, mass	prosperity, energy for human and for biotic activity, structure of ground on which to build
Biological	Life function	food, air, water and soil quality, hygiene, pollution, waste, green areas, biodiversity, habitat diversity, shelter, health and health services, gyms
Sensitive	Senses, feeling	comfort, noise, feeling of well-being, feelings engendered by living there, security, counselling service, asylums
Analytic	Discerning of entities, logic	diversity, functional mix, quality of analysis for planning, knowledge, education services, research centres, universities
Historical	Formative power	built heritage, technology employed, creativity, museums, archives
Lingual	Informatory, symbolic representation	communication, collaboration and networks, advertising, the media, monuments
Social	Social intercourse, social exchange	social relationships, social climate, cohesion, competitiveness, social register, clubs and societies, recreational places
Economic	Frugality, handling limited resources	efficiency, attitude to finance, use of land and of resources, signs offices, banks, stock markets, industrial plants, property-market interests
Aesthetic	Harmony, beauty	beauty, harmony, architectonic style, decoration art galleries, theatres
Juridical	Retribution, fairness, rights	democracy, rights, political structure, tribunals, administrative offices legal institutions, regulations and other policy instruments, laws, ownership,
Ethical	Love, moral	equity, solidarity, sharing, participation
Credal	Faith, commitment, trustworthiness	shared vision of what we are and of the way to go, effectiveness, equilibrium, churches, synagogues

Table 1. The list of modal aspects and their correspondence meaning in urban sustainability.

In planning and the built environment threats to sustainability, usually, come from ignoring the laws of one or more aspects [12]. This framework provides a guide for managing the process of evaluating urban sustainability, improving both technical and communicative evaluations in planning.

From a technical point of view, it helps to consider "*if*" an action is in line with the laws of all aspects in an integrated and balanced manner over the long term. Within a communicative ideology, it offers a basis for building a common understanding of the decision making problem by helping the process of getting information both, technical and non-technical. This information can be mapped onto a decision support matrix, such as the one illustrated in Figure 1.

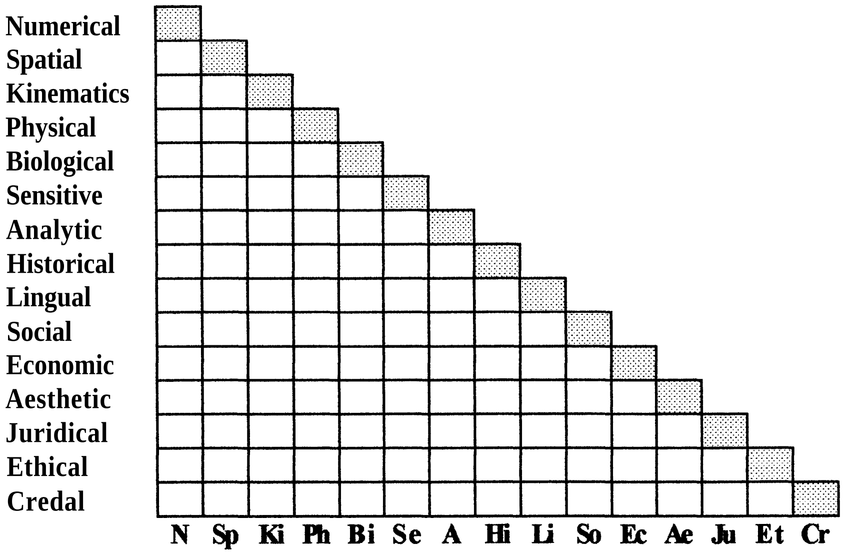

Figure 1. The decision support matrix for organising the information

Each entry of this matrix can be organised as a potential data-base which would include all the information and point of views for decision making specifically related to the links between two modal aspects. Gaps in, and the limitations of, available information on urban sustainability can be immediately highlighted, as specifically illustrated in the application in the following section.

Finally, the matrix takes into account the ***analogy*** relationship between the modal aspects by considering each of them as a source for all the information which can be produced and organised by row. This means that the second half of the matrix does not need to be considered [4]

An illustration of the multi-modal framework may illuminate the benefits of using it in planning evaluation.

2.2 An application of the multi-modal framework for illustration

In this application, the multi-modal framework will be applied to the available technical information on urban sustainability, highlighting the gaps and the main limitations of current scientific knowledge on this subject.

An effective representation of current technical information on urban sustainability is given by the lists of sustainability indicators developed by different international organisations such as OECD [13], United Nations [14], EU Expert Group[15] and European Environment Agency [16].

The aim of all these indicators is to illustrate current environmental problems, identifying their causes and effects, in order to improve decision making processes and assist local administration in finding possible solutions and correct strategies for environmental and social problems [17]. Sustainability indicators should represent both a fundamental vehicle for improving communication within the local community and an efficient technical tool for supporting decision making process.

In accordance with Agenda **21** [18], the selection of indicators should be operated through a bottom-up approach where citizens play a crucial role in identifying the more appropriate ones. However, many European countries has adopted a top-down approach, leaving to experts the responsibility of this choice.

A detailed analysis of the lists of sustainability indicators suggested at European and International levels [**13, 14,** 15, 16] leads to the following results [4,12]:

- The focus on the environment rather than sustainability. Mostly of the selected indicators are related to a description of the environment as such, without identification of the multiple effects this state has on human and natural resources. This often leads to immediate and short term solutions rather than to a prevention of negative effects.
- The unique utilisation of quantitative measures for describing sustainability in the built environment. All the selected indicators are quantitative and statistical in nature. This is a very narrow way to represent the problem which leaves uncovered a large number of fundamental aspects, putting more emphasis on certain issues than others.
- The failure in their aim to integrate all the dimensions of urban sustainability, i.e. environmental, social and economical. One reason of this problem may be that rigid and definite classifications usually leads to difficulties in defining interactions and relationships between sub-systems. A second reason is related to a difficulty in defining sustainabiljtv in substantive terms. **This** assumes different meanings in relation to a ***bottom-up*** approach, based on public participation, or a ***top-down*** approach, based on expert opinions.

These results are made particularly explicit by using the framework of Table **1** and the decision support matrix of Figure **1** for classifying the selected lists of sustainability indicators, as illustrated respectively in Table 2 and Figure 2.

Table 2 reports most of the selected indicators according to the fifteen modal aspects. It uses the numerical dimension as *an idiom* (the only one) for representing all the other aspects of reality, in accordance with the ***analogy*** relationship between the modal aspects. In other words, Table 2 can be considered as a base for developing the first column, i.e. the numerical, of the decision support matrix in Figure1.

Figure 2 shows the disharmonies in the distribution of numerical indicators along the modal aspects, illuminating the ignoring and unbalance in our scientific understanding of urban sustainability. Major information is included in the kinematics, biotic and economics while the aesthetics and the credal are empty. This lack of homogeneity in the information included within each dimension corresponds to some gaps in current technical knowledge.

A technical explanation of this lack is that the effectiveness of an aspect as an idiom, varies and the degree of correspondence declines as the distance between one aspect and another increases. Thus, the numerical aspect is not a very suitable idiom for the more soft and normative aspects, such as the aesthetical, the juridical ones, and very few quantitative indicators may be found in this area. Closer aspects, such as the ethical, are more useful for explaining juridical aspect [8].

Modal Aspects	Numerical indicators suggested by European and International Organisations
Spatial	urban land-cover (total area; total built-up area; open area; transportation network); derelict areas; urban renewal areas; population density; etc.
Kinematics	modal split; commuting patterns; traffic volume; transportation of goods; proximity to urban green area; percentage of streets according to pedestrian accessibility criteria, number of trips pro capita in average length per mode, percentage of population living close to public transport; length of pedestrian streets; length of cycle-roads; percentage of public transport of goods (ton/km); number of private cars; length of fast motor-way; length of rail-way; length of public transport; number of people using public transport (millions); percentage of transport network on the total urban area, percentage of people moving in the town over the total urban population; etc.
Physical	energy consumption; energy production plants; surface water; percentage of listed natural areas water consumption pro capite related to different uses; hectares of ground for agriculture; etc.
Biological	mortality rate, population growth rate, number of inhabitants; production of special waste; percentage of enterprises for recycling; amount of recycled material over the total waste, waste treatment and disposal; biodiversity (e.g. number of bird species); presence of green areas (e.g. percentage of people owning a garden); air quality (long term SO2 + TSP, short-term concentration: 03, S02; TSP); quality of drinkable water; tons of white water; quality of water where to swim, quality of water on and under ground; wastewater, soil quality; contaminated lands; etc.
Sensitive	level of noise; noise exposition up fixed level of decibel; mitres square of living space for person; average floor area per person; percentage of housings without domestic infrastructure (gas, electricity, water); criminal rate, racism's actions rate, rapes rate, percentage of people feeling unsecured to go out at night, fatalities and causalities from traffic accident; etc.
Analytic	alphabetisation rate, library use rate (number of consulted books); number of research centres in the area; etc.
Historical	number of listed buildings; percentage of buildings needing a restoration; etc.
Lingual	number of principal phone-lines every 100 inhabitants; presence of information knowledge database
Social	percentage of population participating to neighbourhood activity; percentage of population using recreational services (artistic manifestations); etc.
Economic	distribution of income pro capite; rate of GNP growth pro capite; relation between housing price and rent, percentage of people living in a state of poverty; exported goods and services; imported goods and services; energy consumption pro capite per year; fuel consumption in £; energy consumption per sectors and sources; employment rate percentage of employment opportunities in the top-ten enterprises; real unemployment;; average distance from work; percentage of recycled paper in public offices; number of enterprises having environmental permission; public expenditure and private investment for the environment; percentage of expenditure for environmental protection on the GNP; percentage of government funds deriving from taxes and subsides; etc.
Aesthetic	
Ethical	number of younger participating in voluntaries activities and community services; etc.
Juridical	percentage of population voting in the administrative elections; number of juridical actions and advising for violation of environment regulations; percentage of control on economic activities without contravention, etc.
Credal	

Table 2. A multi-modal classification of quantitative sustainability indicators

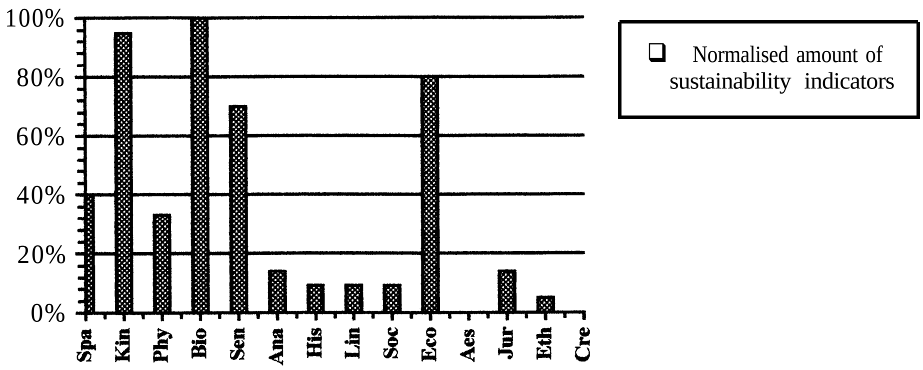

Figure 2. Distribution of sustainability indicators along the modal aspects

3 Conclusion and further research

The multi-aspect nature of urban sustainability requires an improvement of current approaches in planning evaluation, both technical and communicative, and the integration of the artificial (but time-honoured) separation of subject (human system) and object (physical system)]. .

The main advantages in adopting the multi-modal system thinking for evaluation are the following: a) it links all relevant evaluation criteria and indicators in a holistic manner, nesting them in an ordered manner; b) it considers different levels of information, avoiding ignoring and imbalance among them; c) it provides structure and continuity for the evaluation, helping discussion among the parties concerned.

This approach has also been used as a classification system for sustainability indicators suggested by different European and International Organisations. This analysis of sustainability indicators has shown a vision of the problem which is only quantitative (one-dimensional) and technical, therefore partial and sectorial. In addition, it has illuminated a lack of information in many aspects of urban sustainability and the consequent need to improve both, current scientific knowledge in this field and current participatory approaches in decision making. In particular, the development and management of soft and unstructured information may be supported by interactive and communicative techniques, such as the multi-modal framework illustrated in this paper.

Further research is underway for developing a knowledge based system on the base of this study.

4 References

1. Lichfield N., Kettle, M. and Whitbread M. (1975) *Evaluation in the planning process,* Oxford, Pergamon.
2. Healey, P. (1996) The communicative turn in planning theory and its implications for spatial strategy formation, in Fisher, F. and Forester, J. (eds) *The Argumentative Turn in Policy Analysis and Planning,* Durham, Duke University Press.
3. Guba, E.G. and Loncoln, Y. S. (1989) *Fourth Generation Evaluation*, London, Sage
4. Lombardi, P. (1996) Sustainability indicators in urban planning evaluation, in Proceedings of the Third International Workshop on *Evaluation in Theory and Practice,* London, 19-21 September 1996, Kluwer Academic Publishers (in press).
5. Khakee, A. (1996) The communicative turn in planning and evaluation, in Proceedings of the Third International Workshop on *Evaluation in Theory and Practice,* London, 19-21 September 1996, Kluwer Academic Publishers (in press).
6. Camagni, *R.* (ed.) (1996) ***Economia e pianificazione della città*** *sostenibile, II* Mulino, Milano.
7. Brandon, P. S., Lombardi, P., Bentivegna, V. (eds.) (1997) *Evaluation of the Built Environment for Sustainability,* Chapman&Hall, London.
8. Ravetz, J.R. (197 1) *Scientific Knowledge and its Social Problems,* Oxford, Oxford University Press.
9. de Raadt, J.D.R. (1991) Cybernetic Approach to Information Systems and Organization Learning, *Kybernetes,* vol.20, pp.29-48.

lO.Dooyeweerd, H. (1955) *A New Critique of Theoretical Thought,* 4 vols, Philadelphia, Presbyterian and Reformed Publisher Company, Pennsylvania.

11 .Lombardi, P. (1995). Evaluating Sustainability at a local planning level, in Proceedings of the International Research Workshop *CIB* TG-8 on *Linking & prioritising environmental criteria,* Toronto, Canada, pp. 89- 100.

12.Lombardi, P. and Basden, A. (1997) Environmental Sustainability and Information Systems, *Systems Practice,* Vol. 10, No.4.

13 .OECD (1994) Report on *Environmental Indicators.,* OECD, Paris.

14.United Nations (1995) Work Programme of indicators of sustainable development of the commission on Sustainable Development, Paper-United Nation Department for Policy Coordinator and Sustainable Development.

15.EU Expert Group on the Urban Environment (1994) *European Sustainable Cities. Consultation Draft for the European Conference on Sustainable Cities and Towns,* first annual report, Aalbourg, Denmark, 24-27, Commission of the European Communities, Directorate XI, XI/307/94-EN.

16.European Environment Agency Task Force (1995) *Europe's Environment.- The Dobris Assessment,* David Stanner and Philippe Bourdeau (eds), Earthscan.

17.Nath, B., Heans, L. and Devuyst (1996) *Sustainable Development, WB* press, Brussels.

18.United Nations Conference on Environment and Development, (1992) *Earth Summit '92 (Agenda 21),* Regency Press, London.

Productivity and Quality in Renewal of Buildings

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Abstract
Improved productivity and quality in renewal of buildings are not in conflict with a requirement for sustaining the environment, but it requires that the building sector changes its attitude to the handling of innovation and process control. Research on the increasing Danish renewal sector has provided experiences on how to handle these changes. The research work is based on hypotheses and models on productivity documentation, and analyses and improvements are adjusted to the building sector. The practical use is demonstrated on renewal projects, and it is proposed that the principles are transferred to environment research.

Guidelines for contractors and consultants on how to document productivity on different types of projects are developed. They can be used for improving both the competitive power in the companies and in renewal projects, and they simplify the productivity documentation. A new method for step by step reducing the deviations in the productivity analyses helps to zoom in on major problems and search for the best opportunities for improvements. Examples show that efforts must be dedicated to manpower planning instead of to purchasing, and that process planning, requirements, quality and price primarily shall be specified on the different building elements and secondly on the individual contracts.

It is clear from the described examples that there is only little experience in the renewal sector on handling innovation processes from ideas to final implementation of products and processes. We also feel that there is a lack of understanding in some environment research work concerning the basic control mechanism in the building sector. It is our opinion that this has to be changed, if the building sector shall fulfil the requirement for sustaining the environment.
Keywords: Productivity, quality, renewal, roof, labour, cost

1 Introduction

When one looks at the various initiatives of development which have been carried out in the Danish building sector it is striking that the greatest efforts are made in the field of development of products based on new ideas. Only a small part of the development is to be found in the implementation of the best of the tested ideas and in the field of development of better methods and work routines. This low priority for better methods is probably a consequence of the fact that the development activities, which are the easiest to grasp, are furthered quite subconsciously, whereas the activities that are difficult to understand and which demand cooperation of various groups, subconsciously are given a lower priority.

Already in 1637 the French scientist and philosopher René Descartes wrote about this problem in *The Method* [1]: *"I started with the most simple objects which were easy to grasp and then progressed little by little to understand the most complex ones"*.

In the research on productivity and quality undertaken at the Danish Building Research Institute (SBI) we have focused on practical examples which have shown great improvements and which have or might have an influence on the sector as a whole. The research is in addition based on the following two assumptions:

- A new and better method has not been found until it is easily comprehensible and can be made into an example the end-user will choose instead of the old method
- The success of a method depends on the internal cooperation in building projects as well as on clear relations between “customer need” and requirements

The objective of the development is to find common methods which can be used to document individual solutions, to compare several projects and to point out areas which can be improved. The methods should be simple so that they, with a minimum amount of readjustment, can be used both in technological research and development, as well as in the development of the various companies in the sector.

2 Model for analysis of quality and productivity

The model has been built up based on experiences from quality control, economy control, production control and similar areas in other industrial sectors [2][3][4], and it has then been simplified to a form suitable for the practice of the Danish building sector. The model is based on the scientific traditionwhere qualitative methods often in the beginning are applied within new research areas and then later exchanged with quantitative methods which, step by step, go from the approximations of the first order to more and more complex models.

When comparing such different areas as economy control, production control, quality control and environmental control it turned out that they are all founded on the same general elements. The only difference is that different parameters are used for the control and that different areas are at a different innovation level. It is also evident that a great part of the data is mutual and has many common features. Consequently, it has been the objective of this model to make a common framework which can be used for more than analysing quality and productivity.

Relationship between customer and supplier or the customer-supplier-chain

The model presupposes that the building is to be delivered as a product from the construction parties to the customer, who may be a building owner or the end user. During the building process, it is a question of a chain of customer-supplier conditions covering deliveries of materials, workman hours, services and building parts.

In a customer-supplier relationship the customer's demands andwishes as regards the product are not always identical with what the supplier can deliver. Possibly a gap of opinion on quality and price between the two parties may occur and be visible when the building is delivered. In the same way the consultants make demands on the contractor and the contractor on the suppliers when the work is being carried out. That means that the chain of deliveries and subdeliveries are presented with a chain of demands on which the two parties may have different views and which on delivery might cause some discussion.

Basic elements in the building process

The individual building processes are described based on an input-output model as indicated in Figure 1. The input consists of working hours spent to carry out the working process and raw materials which are included in the final product, and capital including operating equipment supporting the process. The output consists of the product or services delivered from the process, conditions of delivery and the price of the product - the result of the process.

The individual building process and services can be divided into a number of sub-processes which together contribute to the execution of the total building process. In each sub-process a processing of goods and services takes place and between the sub-processes a stream of information and exchange of materials and services take place. In each sub-process and each exchange of information or materials, development or changes may occur.

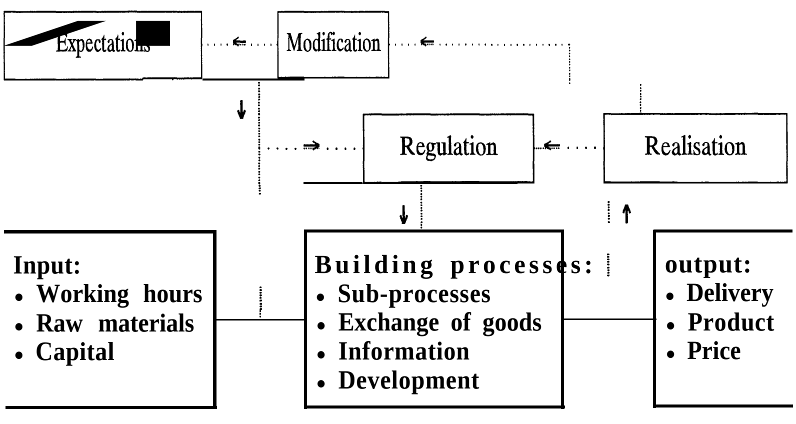

Figure 1. The simple controlling model for the design, planning and building process and also used in the analysis.

It is a prerequisite for controlling a building process that some requirements and expectations as to the result of the process are made. Towards the end of the process the accomplished values are measured and a comparison of the two values can be expressed in a deviation which, depending on size and importance, may result in the following decisions: No reaction, a regulation of the process or a modification of the expected values.

Productivity parameters of the control

The parameters included in the control of a building process cover the consumption of resources spent in the process and the final result. If these two main parameters are set in proportion to each other you get the parameter model for productivity which in this context describes the building process viewed from the side of the building sector and not from that of the client. In this relation a decreasing consumption of resources will give a rising productivity and an increasing building process result will also give a rise in productivity.

The consumption of resources is further divided into the three parameters of resources: Time consumption, building products and operating capital. The numerator of the parameter model which describes the result of the building process is also divided into three parameters: Date of delivery and duration, standard & quality as well as volume and quantity. Under standard & quality the functions and properties as well as architectural and aesthetic qualities and environmental standard are described, and they are probably the most difficult parameters to handle.

3 Methods for comparison of building elements of several projects

As mentioned in the previous section, the model presupposes that a building can be divided into a number of coherent building processes, and measured by the productivity parameters the individual building project in its entirety can be described. These two items are further described in the subsequent description including how in practice product- and process-key-figures for the individual building processes are fixed and are to be used for instance for benchmarking.

Division a project into building parts and contract parts

In Denmark it has for many years been the practice that the various building projects are divided into contracts and often the activities of the contracts have been subdivided according to SfB-classification [5]. In recent years this practice has undergone some changes as several consultants today also use a division of the building project into elements as a base.

The division into building elements is the general and stable division focusing on delivery in close connection with the end user, whereas the division into contract parts focuses on the cooperation between parties in the building process. At the moment a common division into building elements is demonstrated on new building and on renovation of small building properties. Building elements takes place in units which are visible to the building and shall be clearly limited geometrically, so it is possible to locate them in the project under the following main areas:

- *Property and land* of the building as well as surrounding areas and installations and small buildings outside the housing property
- *Building*, its outer structures, the load-carrying structures and installation elements for distribution and supply in the building
- *Flats* and ***rooms*** of the building such as living-rooms, stairs and common rooms complete with installations
- ***General activities*** regarding the building project which do not belong to the other items, but concern design, administration and financing of the project.

Product- and process key figures for benchmarking

A central task for the reseach on productivity and quality development, i.e. to render it visible, and a means to make the sector visible is to work out various key figures which the sector can refer to - also called benchmarking. A key figure system is based upon the fixed quality and productivity parameters with reference to the individual building elements and in relation to the different uses and purposes of the buildings. There are two types of key figures - product-related key figures and process-related key figures. The product-related key figures relate to end user and their communication with the consultant attached to the design and delivery of the building, whereas the process-related key figures relate to the construction parties to further the improvement of contract parts.

As an example, the process-related key figure for the entire roof construction can be expressed in proportion to the size of the roof area, whereas the product-related key figure is expressed in proportion to the total floor area. That means that for a one-storey house these two figures will be the same, but the higher the number of floors of a building, the lower the product-related key figure will be.

Minimizing ***deviations in analysis of key figures***

The key figures are mean figures of similar types of buildings. In order to render the results of the analysis and the development even more visible the deviations between the individual buildings are set down. This can be done by means of an SBI-method called "Stepwise Minimizing of Deviations" (SMOD).

The principle is well-known within quality control and production control, but also within various sports, e.g. shooting. Through an analysis of a number of measurements, the average and standard deviation are to be calculated and put in proportion to the goal. Then a search for different factors which can reduce the standard deviation and the distance to the desired goal is the next step. If such an important factor is found it has to be eliminated and one can start a new round of minimizing of deviations.

Table 1. *Stepwise* ***minimizing of deviations*** *(SMOD)* ***in the analysis on 88 roof constructions in Copenhagen*** *[6].* ***The values are expenses on direct construction work in*** *DKK-*
kroner *excl.* ***VAT and in*** *1995-prices.* ***General activities will add 44*** *%* ***to these expenses.***

Type of renovation	Number of projects	Process-related key figures for roof Expenditure per roof area in kr/m²		
		Average	Standard deviation	
1. Minor repairs	7	256	55	21 %
2. Repairs, min.	2	560		
3. Repairs, max.	2	1.455		
4. Renewal, min.	18	1.755	575	33 %
5. Renewal, max.	53	3.190	944	30 %
5.1 Non-utilized attic	27	2.759	704	26 %
5.2 Utilized attic	26	3.637	964	27 %
Sub-total for 82 projects	82	2.518	1.278	51%
Projects not included:				
Atypically expensive projects	4	from 5.187 to 6.946		
Projects without renewal	2	0		
Total for all 88 projects	88	2.615	1.485	57 %

The stepwise minimizing of deviations has been applied in analyses of 88 renewal projects in Copenhagen [6] and an illustration of the method on roof construction can be seen in Table 1. The standard deviation for all 88 projects is 57 %. The first step is to remove atypically expensive projects and projects where no renovation has been done one comes to 82 projects with a standard deviation of 51 %. The second step is to divide the renovation into 5 types, and the standard deviation for each type is calculated to 21 - 33 %. One type is very large and consists of 61 % of the remaining 82 projects and with a total standard deviation of 30 %. The third step divides the 53 projects into two sub-groups - one for buildings with non-utilized top floor and one for buildings with utilized top floor, and the standard deviation for the two new and even groups was reduced from 30 % to 26 % and 27 %.

4 Method for comparison of activities in a project

The method has been applied to a 4-storey building property with 9 flats in Odense, which were totally renovated in 1995 [7]. In the test it was the wish to examine the quality of the design process and to find important areas where it would be advantageous to start improvements or initiate further investigations.

Relative deviations in the planned workman hours

The project was divided into 8 building elements and 5 contracts and into many different activities within each of these. Out of the 40 combinations of building elements and contracts, work was only carried out in 27, and for each of these, expected and realised data were collected for each productivity parameter. On this basis the relative deviation for each combination and parameter has been calculated by means of the following expression:

Relative deviation = (Realised - Expected) /Expected

Table 2. *Relative deviation for workman hours in the test project in Odense [7]. The deviations in bold are the most important ones, which should be submitted to improvement.*

Building elements	Contracts in the renewal projects					Contract total
	Mason	Carpenter	Painter	Plumber	Electrician	
1. Roof	-5 %	**119 %**	*	-27 %	*	33 %
2. Facades	10 %	10 %	(1380 %)	*	*	-1 %
3. stairs	18 %	93 %	-33 %	*	-20 %	33%
4. Bath and toilet	12 %	-61%	-10 %	-47 %	-70 %	33%
5. Kitchen	-1 %	20 %	76 %	0 %	-28 %	17 %
6. Heating	*	*	-20 %	**90 %**	*	83%
7. Living-room	*	-37 %	308%	(115 %)	335%	120%
8. Building site	*	*	*	*	(160 %)	160 %
Elements total	-4 %	-36 %	71%	-6%	17 %	16 %

Note: '*' no work has been carried out, '()' small numbers of hours

In Table 2 an example is given of how the result can be presented for the calculated relative deviations. The presentation points out areas where improvement efforts probably would be of most value by finding the greatest deviations for the combinations of a considerable size. 5 areas have been pointed out, which are marked in bold, and these cover a total of 37 % of the total number of workman hours.

That means that if it is possible to find the reason and limit the deviation in these 5 areas, a marked improvement of the result of the design and planning will take place as far as future projects are concerned. In the same way all the other parameters have been studied one by one to find possibilities of improvement and the same presentation has been used to make it easier for the parties to find the most important areas of future efforts.

Potential cost reductions concerning labor cost compared to building products

If, on the contrary, one has to compare one productivity parameter with another to find out where future efforts are best applied, a comparison of various divisions can be made by means of the same data. As an example, the difference is shown between the labour cost and the expenses for building products.

In the renovation project in Odense [7] the labour cost amounts to 47 %, the expenses for building products amount to 49 % and operation cost amounts to 4 % of a total realised workman expense of 2.690.670 DKK-kroner. That means that improvement efforts regarding the consumption of resources should either focus on labour cost or on building product expenses. If one looks at the relative deviations for both labour cost and building product expenses it is possible to set up two distributions which can be compared, Figure 2 and Figure 3. In each distribution the deviations for the individual building elements, contracts and activities are weighted in proportion to their share of the total expenditure.

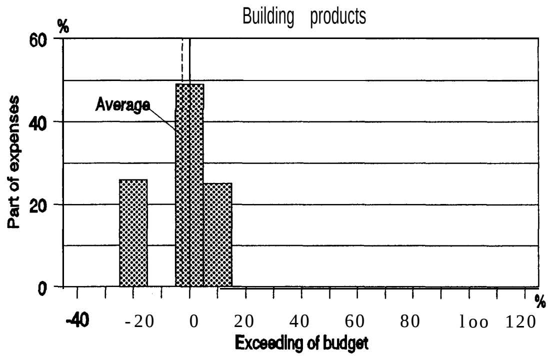

Figure 2. Distribution of budget-exceeding for buildingproducts (49 % of the total workman-expenses).

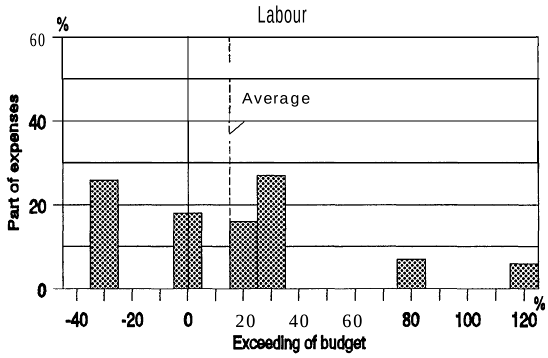

Figure 3. Distribution of budget-exceeding payroll expenditure for labour (47 % of the total workman-expenses).

As far as building products are concerned, the average is seen to remain at a lower consumption of 3 %. For 49 % of the expenses for building products the expected values have hit the realised values, and the largest deviation is -20 %. Conversely, the average of the labour cost seems to be in excess of 15 %, and the deviation is large. For instance 5 % of the expenses have an excess of up to 120 %. Comparing the two distributions it is evident that labour costs are the most difficult ones to plan, and that it will be here that the possibility of improvements will be the greatest. The interesting aspect of this conclusion is that it is in clear contrast to the efforts spent on development, the largest efforts normally being spent on the field for products.

As shown in the above example, the important effort areas are pointing at areas where the deviations are the largest. The procedure of the improvement work and of better analyses is to try to minimize deviations.

5 References

1. Descartes, René ***(1637) Om metoden,*** Gyldendal, ISBN 87-00-24704-9
2. Sullivan, L.P. ***(1986) Quality Function Deployment,*** Quality Progress, June p. 39-50
3. IS0 9004 (1988) Q***uality management and quality system elements,*** Dansk Standard
4. Dam, A., Riis, J.O. and Thorsteinsson, U. ***(1994)*** *Integreret produktudvikling - fremgangsmåde*, Polyteknisk Forlag ISBN 87-502-0764-4
5. CIB (1977), *SfB-classification*, CIB Report no 40, Dec.
6. Bertelsen, N.H. ***(1998)*** *Kortlægning af byfornyelsessager* SBI, F5-185, Part 10
7. Bertelsen, N.H. ***(1997)*** *På vej* ***mod enproduktiv*** *byfornyelse* SBI, F5-189, Part 10