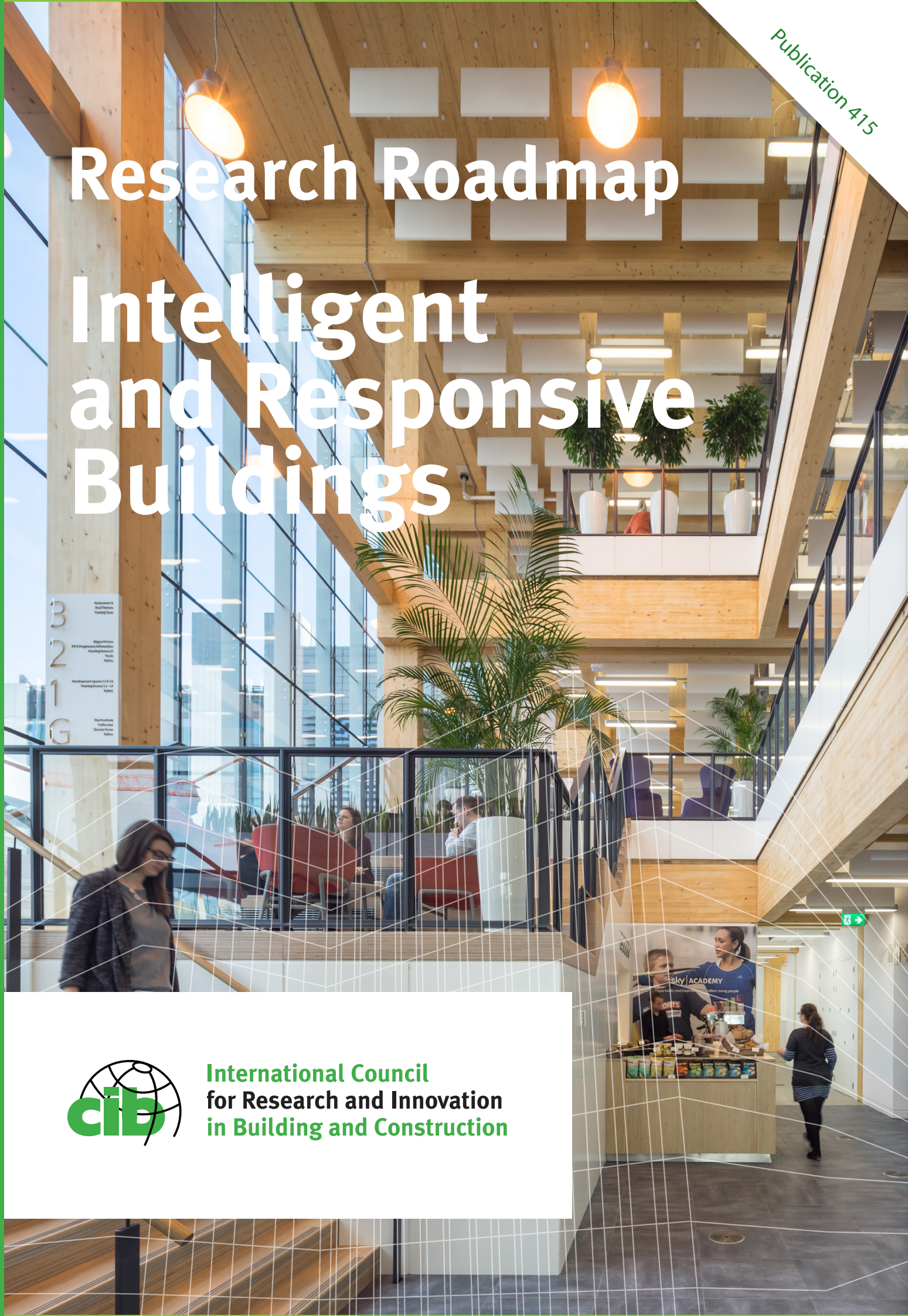
Publication 415

Research Roadmap

Intelligent and Responsive Buildings



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CIB W098 Research Roadmap for Intelligent and Responsive Buildings

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1. Conceptual Framework

Derek Clements-Croome

> *An intelligent building is one that is responsive to the requirements of occupants, organisations and society. It is sustainable in terms of energy and water consumptions besides being lowly polluting in terms of emissions and waste: healthy in terms of well-being for the people living and working within it; and functional according to the user needs.*
>
> Clements-Croome, 2009

Intelligent buildings need to be sustainable. This means sustaining their performance with respect to energy, water, waste and pollution for future generations. Beyond this, intelligent buildings should be healthy places to live and work in; be equipped with appropriate reliable technology; meet regulations; respond to the needs of the occupants; be flexible, adaptable and durable; give value for money. Architecture provides landmarks in our civilization so their visual appeal remains important too.

Buildings will contain a variety of systems designed by people, and yet the relationship between buildings and people can only work satisfactorily if there is **integration** between the supply (design consultants, contractors and manufacturers) and demand (developers, building owners and occupants) side stakeholders as well as between the occupants, the systems and the building. **Systems thinking** is essential in planning, design and management, together with the ability to create and innovate whilst remaining practical. All this requires **holistic thinking**. Table 1 summarises the main characteristics of holistic thing in contrast to an atomistic approach.

Table 1: Atomistic Technical and Holistic Socio-technical Approaches to the Built Environment [based on Munro 2011]

	Atomistic	Holistic
Nature	• Narrow: concentrates on individual elements	• Broad: elements seen as inter-related; interoperability important
Perspective	• Individual systems in isolation • Single discipline outlook	• Whole system • Interdisciplinary and transdisciplinary outlook
Cause and Effect	• Looking only at immediate effects • Short chains of causality	• Separated in space and time • Long chains of causality, ripple effects, unintended consequences, feedback effects

Style of Recommendations	• Technocratic • Regulation and compliance	• Socio-technical • Beyond regulations
Results (observed and sought)	• Narrow range of responses to user's needs • Defensive management of risk • Command and control management; frameworks and procedures; squeezing out professional discretion and creativity • Compliance culture • Focus on standardised processes, frameworks and procedures	• Flexible responses to meeting user's needs • Acceptance of irreducible risk • Supportive management encouraging creativity, discovery and enterprise • Comprehensive feedback • Focus on building users their needs with pathways giving high value outcomes such as good well-being and high productivity

A lot of terms are used. Should we say intelligent or smart buildings? Then there is the sentient building which describes how well the building responds to the occupants changing needs. A sentient building should be measured continually with a sensor network which can predict and also activate change according to circumstances and user preferences. With respect to cities, the automation and digital aspects especially in information and communications technology are the smart elements which are important but a building needs also to respond to social and environmental factors and this features the language of low tech passive environmental design. An intelligent building increases the environmental socio-economic value (see Fig. 1).

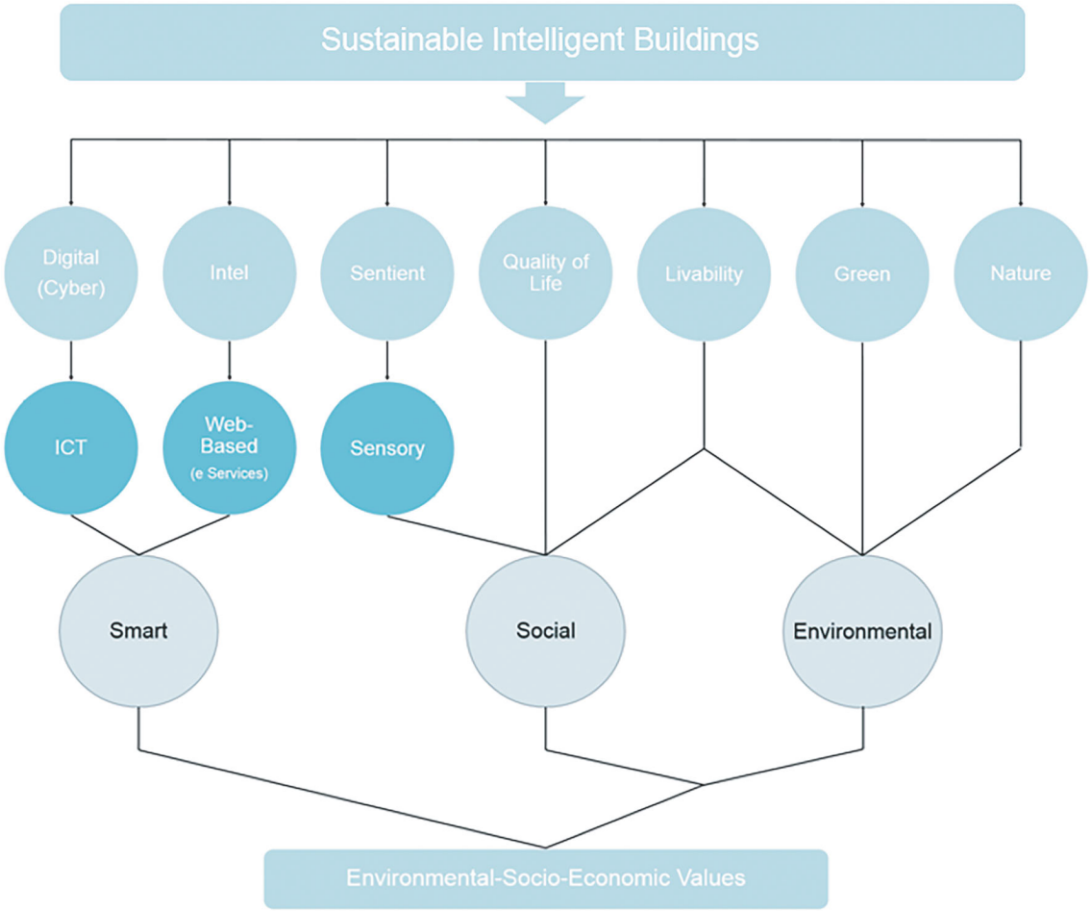

Figure 1. Key constituents of Intelligent Buildings [Clements-Croome 2013, p. 289].

The ultimate objective should be simplicity rather than complexity and this is best achieved by naturally responsive architecture. This not only requires technical ability but also the powers of interpretation, imagination and even intuition. Building Regulations can stifle creations but are necessary to set a minimum level of expectation and obey health and safety requirements. However we should aim to design well above these conditions. After all, buildings form our architectural landscape and they, and the environment they generate, should uplift the soul and the spirit of those people within them as well as those who pass by them. Clements-Croome [2018] proposes a Flourish model as a model for user centred design.

The creation of shared visions, effective teams, clear and robust design and management processes ensures that the intelligent building will effectively demonstrate in use the purpose for which it was conceived. Times are changing as technology and society evolve so there needs to be a long term outlook by the team. Key innovation issues for intelligent buildings include sustainability (energy, water, waste and pollution), the use of 3D and 4D printing technologies, the use of information and communication technology, robotics, embedded sensor technology, smart-materials technology including nanotechnology, health in the workplace and social change.

Facades using smart materials for example will provide sophisticated forms of feedback and high levels of control besides regulating heat air and light transmissions. By coating and embedding materials with nano-particles we will be able to specify material properties much more easily [Pacheco-Torgal et al 2013; Pacheco-Torgal and Labrincha 2013]. Structures with zinc oxide nano coatings for example can accelerate heat dissipation. Self-healing materials will revolutionize facades in the future. Pelletier and Bose [2010] describe how a concrete matrix embedded with capsules of sodium silicate healing agent can repair cracks by the sodium silicate from the ruptured

capsules interacting with the calcium hydroxide in the concrete to form a gel which seals the cracks.

In contrast one must not forget that basic materials like hemp, straw, rammed earth, waste composites and wool and seaweed bricks all offer sustainable solution possibilities. Cloth made from lotus stems was reported in the Financial Times 9 March 5th/6th 2011. Novacem concrete is a low embodied energy material developed at Imperial College in London. In the future graphene new material can be expected to make its impact on façade designs.

However innovation should be an enabler rather than an end in itself. Passive environmental design is equally important so that the energy demands are minimized by using natural means such as mass, orientation and building form to capture sunlight, fresh air and rain water. But we cannot ignore the rapid developments in digital technology. In the words of the Hong Kong architect James Law:

> *In the 21st Century, buildings will be different from 20th Century. They are no longer about concrete, steel and glass, but also the new intangible materials of technology, multimedia, intelligence and interactivity. Only recognizing this will bring a new form of architecture to light, namely a Cybertecture.*

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Clements-Croome, D. (ed.). (2018). Creating the Productive Workplace: Places to Work Creatively. 3rd edn. London & New York: Taylor & Francis.

2. Future of Intelligent Buildings: A Critical Debate on Key Performance Indicators

Amirhosein Ghaffarianhoseini, Derek Clements-Croome Ali Ghaffarianhoseini, Husam AlWaer, John Tookey

2.1 Conceptual framework

In recent years, design and implementation of greener and smarter buildings has indicated growing trends [Ghaffarianhoseini et al. 2016; Xie et al. 2017]. This is evidently observed in several recent practices globally, on top of the significantly increased number of research publications in the areas of sustainable and intelligent buildings.

Notwithstanding the widely well-known concepts of green, sustainable and intelligent buildings, their embedded essence and ultimate impacts are evolving and adjusting to cultural and social changes. Current body of literature confirms that, advancement of intelligent buildings (IBs) is frequently claimed to be a promising solution towards achieving enhanced building performance. While being efficiently equipped with state of the art technologies, ICT, and automated systems, IBs are highly responsive to the needs of their occupants besides being optimally operational. IBs have also proven to be capable of deploying sustainable design initiatives to enhance the overall performance of buildings and maintain an acceptable level of occupant comfort [Ghaffarianhoseini et al. 2016; Clements-Croome 2013]. Nevertheless, IBs have been interpreted in many diversified ways. This complex has led to the true potential of IBs not being fully revealed [Ghaffarianhoseini et al. 2016; Clements-Croome 2013]. Research endeavours to shed light on the state of the art of IBs, the most crucial agendas related to their current development, along with their future directions, as illustrated in Figure 2. As initially suggested by AlWaer and Clements-Croome [2010] who developed a detailed set of

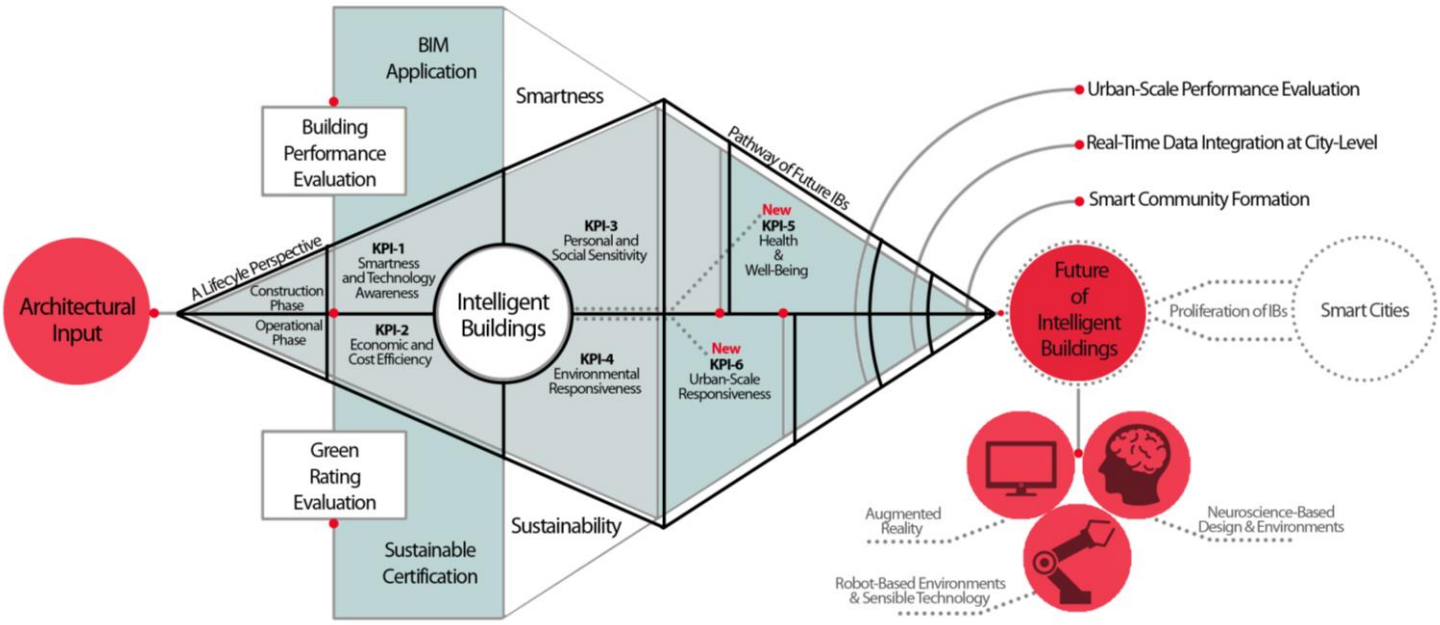

Figure 2. State-of-the-art Overview of Pathways towards Formation of Future IBs

key performance indicators (KPIs) for IBs and later expanded by Ghaffarianhoseini et al [2016], and Clements-Croome [2018] to include health and wellbeing and urban scale responses.

2.2 State of the Art

Several recent studies endeavoured to define IBs, identify their core attributes and set platforms for analyzing their effectiveness [Clements-Croome 2018]. Concerning one of the most recent representation of IBs, six main KPIs are defined [Ghaffarianhoseini 2016]:

KPI-1) Smartness and Technology Awareness,
KPI-2) Economicst and Cost Efficiency to give high value,
KPI-3) Personal and Social Sensitivity and,
KPI-4) Environmental Responsiveness.
KPI-5) Health &Well-Being and,
KPI-6) Urban-Scale Responsiveness.

IBs should go beyond automation and performance dimensions, in order to address a multi-dimensional set of criteria. This proposal suggests integration with emerging technologies in order for IBs to become more responsive to users' needs, value driven and productive [Clements-Croome 2018]. These are on top of becoming adequately adaptable to social and technological changes. This pathway to achieving smarter environments not only requires deploying cutting edge technologies (i.e. use of augmented reality (AR), intelligent energy management systems and/or electroencephalography (EEG) integration) [Vecchiato et al. 2015; Zhou et al. 2016], new design initiatives (i.e. biomimicry design) [Zari 2016] and advanced digital systems (i.e. real-time data sensor integrations) but also needs smarter users and professionals. Therefore, it is important to clarify the interrelated and collective roles of users and communities plus enlightening the interconnected responsibilities of professionals and academicians, in order to achieve the outlined targets.

2.3 Future scenario

Are we aware of the current challenges and drawbacks towards development of solid future IBs?
Do we know the exact degree of necessity on the progression of future IBs?
Are construction professionals and building scientists aware of their role in development and maximizing the ultimate impacts of future IBs?

With the focus of recent studies on the sick building syndrome and the need for healthy buildings [Xie et al. 2017; Clements-Croome 2018; Heidari et al. 2017], the significance of developing healthier IBs, to achieve a higher level of comfort, well-being and productivity [Clements-Croome 2017], is emphasized on. Indeed, the healthy design concept is foreseen to become a focal element for future development of buildings. This is primarily based on its potentials for health improvement, users satisfaction and the associated economic gains. Besides, as smart cities are becoming a main focus of governmental sectors [Deakin & Al Waer 2012; Albino et al. 2015], there is a fundamental need to fill the existing gap between IBs and the smart urban future. As a result, IBs should also be evaluated from an urban-scale perspective to ensure their contribution at city-level. In fact, proliferation of IBs plays a key role towards achieving a truly smart city. This is clearly alongside the urgency for smart infrastructures [Albino et al. 2015]

2.4 Development strategy

Future IBs demand coherent incorporation of cutting-edge digital technologies and building design in order for their true benefits to be extended. In particular, with the emergence of AR in the architectural context, from conceptual design and development to the operational phase, integration

of AR can be an inherent attribute of future IBs. IBs, as the embodiment of highly automated living environments, can become more operationally resourceful and user friendly once deploying AR. Visualizing real-time building and city data in an indoor living environment can be seen as a basis for new methods of maximizing IBs' potentials based on the virtual interactions of users, buildings and urban areas. On the other side, with the emergence of robotics in architectural design and construction, IBs can not only benefit from a more efficient development process (i.e. use of robotics in off-site construction, prefabrication phases and parametric design), but can also be equipped with robot-assisting living environments during the operational phase to enhance safety, security and comfort. Furthermore, from a neuroscience perspective, future IBs not only need to be aware of their impacts on comfort, well-being and satisfaction of occupants, but also should be cognizant of occupants' mood, sensation and feeling via monitoring the brain responses of their users using EEG. Meanwhile, the importance of integrating IBs with Building Information Modelling (BIM) for life-cycle design, operation and maintenance of buildings is signified [Ghaffarianhosein et al. 2017]. Thus, presenting an interdisciplinary development strategy, IBs of future will push the current boundaries to autonomously receive and analyze the real-time impacts of their embedded living environments on the mental responses of theirs users and their health status, plus their influence in the urban-scale performance of the city. This can result in development of ultra-healthy IBs for more tangible contribution to the well-being of occupants and the performance of a city.

2.5 Research Contribution

IBs should be seen as a research-based evolutionary entity that requires continuous upgrade and incorporation of new initiatives both from professional practice and academic perspectives. Literature presents that IBs were repeatedly suggested to become the main umbrella encompassing several targets for achieving green, energy efficient, zero energy, zero carbon, smart and digital built environments. This allows synchronizing all attributes in one set of database for a collective contribution to the next stages of IB development. Above this contemplation, to the best knowledge of the authors, no or very insignificant number of studies have attempted to discuss the gap between IBs and smart cities. In fact, for achieving intelligent urban areas as part of a smart city [Albino et al. 2015], despite the existence of several drawbacks towards a massive proliferation of IBs in an urban area, with the aim of large-scale contribution to the goals of smart city, more in-depth analysis on IBs is required to be carried out.

2.6 Research Agenda

There is no doubt that a key agenda of the 21th century is to amplify the awareness and propose practical solutions regarding the impacts of rapid urbanization [Lehmann 2017]. While to some extent, the rapid urban growth in many mega cities and their surrounding context is inevitable, this study suggests that utilization of IBs, once fully assessed from both building and urban scale perspectives, can provide significant positive impacts. In particular, the study demonstrates that IBs embrace a huge capacity for reducing the negative environmental impacts of urbanization, balancing the digital lifestyle of users with living and working environments plus providing healthier indoor living environments and urban communities. The conceptual framework also implies that IBs can be the central point for formation of smart communities and their large-scale performance besides their real-time data integration at city level can uplift the performance of a city. Likewise, it is elaborated that integration of BIM, AR technology, robotic-based environments and neuroscience-based building design are four core lines of future IB developments. These new dimensions of IBs create a wide platform for more in-depth interdisciplinary research to create the IBs of future from architecture, building construction, digital technology and ICT to urban design,

city planning and computational parametric modelling.

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3. Health and Wellbeing oriented Indoor Built Environments for Future Intelligent Buildings

Quan Jin, Holger Wallbaum

Highlight

Aiming to improve the quality of life for living, learning, curing and working in future intelligent buildings in terms of offering advanced indoor built environments, which takes advantage of reliable and supportive technologies, and is rooted in evidence and resilient design thinking and human real demands targeting human health and wellbeing along with low environmental impact and high economic performance over the whole building lifecycle.

Scope

Considering "health and wellbeing" in intelligent buildings, ecologically sustainable design, indoor environmental qualities, smart metering and control strategies, energy efficient technologies as well as user demand are interrelated closely. This chapter discusses the key features for human health and wellbeing in buildings as well as research gaps between the real perception from user side and the measured building performance. Key research questions are put forward that need to be answered. Research and development concerning knowledge, tools and technologies are initiated. Finally, new horizons for the future built indoor environment of intelligent buildings are depicted.

3.1 Status quo

Looking back on the progress of intelligent buildings since the year 2000, the content of quality of life and users' interactions have been being taken into play as one of the evolutionary strategies. Quality of life makes contributions to the key performance indicators of social well-being and economic efficiency and the specific visions of human health and well-being are one of the key criterions in intelligent buildings' classification. Particularly in next generation office buildings, user-oriented lower carbon footprint, and resilient office design solutions are to be implemented for future. A circular design process instead of conventional linear design is created to holistically integrate multidiscipline and diagnose the real demand from users and stakeholders during the whole building lifecycle [Cobaleda Cordero et al., 2018].

Human health and wellbeing are more commonly known as a positive factor to human productivity in particular for offices [Wargocki et al., 2000; Fisk, 2000]. Productivity is one of the key drivers taking the utmost benefits to building stakeholders. High work productivity of the employees and less sick leave absences could be seen as a game-changer in future intelligent buildings and sustainable office buildings [Feige et al., 2013]. If we contribute to reducing the staff costs in the operational phase through energy efficiency measures and a better indoor environmental quality (IEQ), then we can argue for higher investments on energy efficient and innovative technologies as well as human wellbeing. It has been concluded that if only 10% variation is made by our effort from staff costs, 9% cost saving can be realized in total during the operation phase of buildings (see Fig. 3.2).

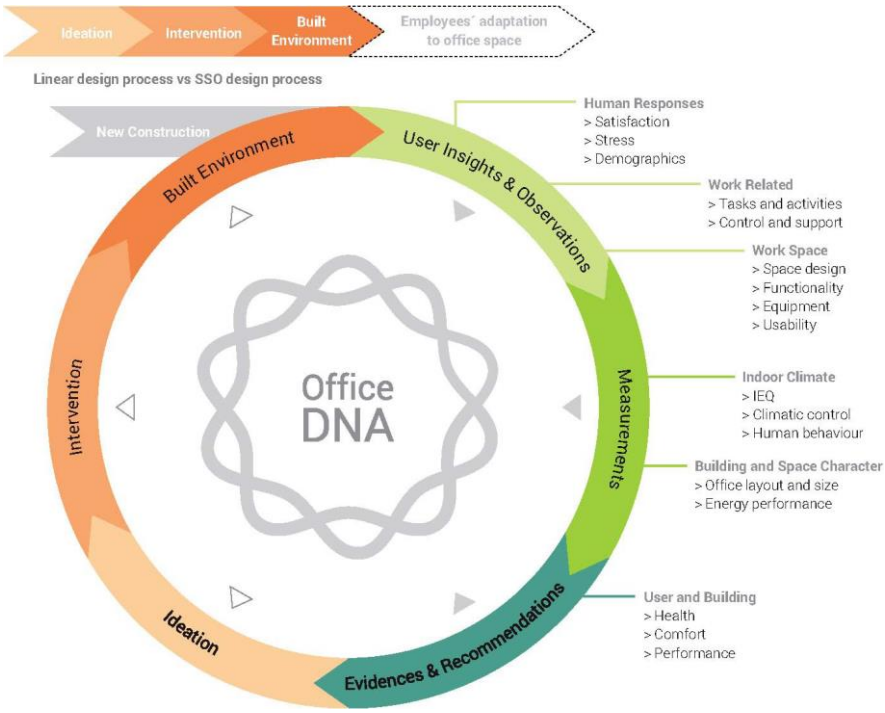

Figure 3.1. Linear design process vs circular SSO design process [Cobaleda Cordero et al., 2018]

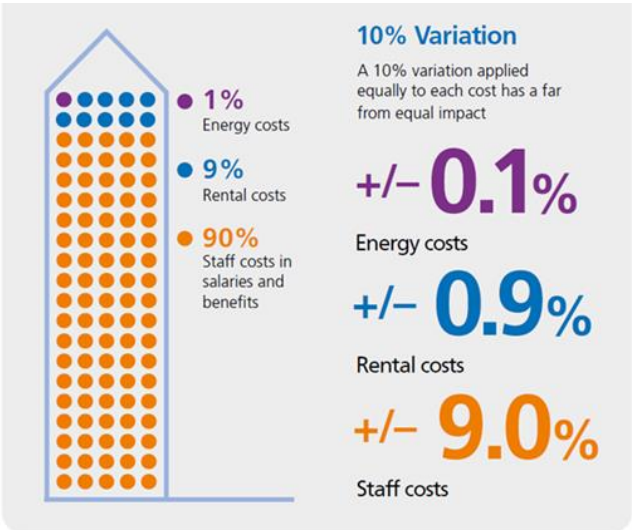

Figure 3.2. Typical business operating costs regarding energy, renting and staff. Source: Health, Well-being & Productivity in Offices, World Green Building Council, Sept. 2014 [WGBC, 2014]

There are more and more indications that a good IEQ in office buildings positively contributes to the well-being of occupants, reduces sick leave days and finally, leads to an increased productivity [MacNaughton et al., 2018]. These so-called co-benefits could be seen as a driver for more energy efficient and healthier buildings in the future - saving costs for both businesses and the society. When concerning the other way round, the consequences of occupant discomfort and ill-health

caused by bad IEQ finally can lead to low work performance and more sick leaves. IEQ in terms of thermal climate, air quality, acoustic and lighting and daylights have a noticeable impact on human comfort, health and productivity which have been selected as mandatory indicator listed in sustainable building rating systems, e.g. WELL, GREEN STAR, BREEAM, LEED, DGNB, Miljöbyggnad, GBI. IEQ needs to be designed and optimized to maximize human well-being and productivity. But sometimes the building design may not create a better indoor comfort and one of the reasons is that we lack of an interdisciplinary study and the cross-disciplines knowledge frame from the physical climate, architectural design, organization environment, as well as social and cultural background of the users.

Beyond IEQ, the other disciplines regarding ergonomic interior design, space function and flexibility use, new user behaviour patterns and work demand need related aspects have been considered [Schiavon & Altomonte, 2014; Kim & de Dear, 2013]. In different building typologies, e.g. offices, apartments, schools, health care centres, elderly home, the specific living and working environments needed from different groups of users should be customized and used for a convenient and efficient living in intelligent buildings. Up to now, the interrelation and interaction of different factors are far from clear, hense a holistic and evidence based design and optimization in future intelligent buildings is exceedingly demanded.

To generate knowledge on buildings and users and their interactions, fundamental studies [de Dear et al., 1998; Zhang et al. 2010] have been conducted on exploring the mechanisms of how humans perceive the indoor environment, what are preferred indoor environment, and what are the key indicators regarding both physiological and psychosocial aspects, for example, skin temperature's reaction to thermal comfort's change and gender's differentiation on the preference [Jin et al., 2016]. Based on new knowledge explored in intelligent buildings embedded smart sensors, meters and automation systems with the human physiological condition, behavioral data and building performance monitoring and information communication technologies have been being extensively applied. An outcome is to match human real demands, preferences and changing behavioural patterns with responsive and adjustable indoor environments and low energy use through intelligent control strategies, for instance, smart grid and demand response control.

Nevertheless, health and wellbeing are more complex on the mental and perceptual levels than it can be predicted only based on the results of measurable building performance parameters [Bluyssen et al, 2011]. There are still many knowledge gaps concerning human real demands and the designed indoor built environments such as a comprehensive understandings of how various factors affecting health and wellbeing, what are the biases existing between human real demand and building performance, etc. However, existing datasets are still limited to identify all related factors and quantify the influencing relations to truly achieve sustainable indoor built environment in different typologies of intelligent buildings. Obviously, there is a demand to gather sophisticated information on occupants' perception and behaviour as well as various building performance related aspects such as energy efficiency levels, the role of smart materials, and potentials of smart technologies. This demand is seen globally but a localisation is required to adequately address socio-economic and cultural differences.

3.2 Research and Development

Global database development: Data collections on energy performance, IEQ and occupant health and wellbeing from existing and new buildings need to be conducted further towards a cutting-edge database set up concerning climate, social and economic conditions. The database development will be a crucial bridge to conquer the gaps between human demand and building performance. More concerns will lie on the data from occupant perceptual and real-time indoor comfort and health, user behaviour and preference, measured energy performances, and from building features on building typologies, user information, indoor environmental qualities, interior components and landscape and low-carbon technologies.

Information communication technology (ICT) embedded data collection and internet of things (IoT): A long-term and longitudinal data collection process is to be promoted to help to visualize the mega field data as "right here, right now" with detailed insights to a dynamic indoor climate and human demands. Embedded ICT equipment and system will allow an intelligent and distance monitoring of various building technologies and equipment. IoT will implement much smarter ways to connect personal equipment and device according to individual preferences of comfort and cost and energy consumed concerns allowing communications between smart meters and smart grid, such as the adjustable orderings of personal heaters, windows, self-ordering fridges, washing machine at low energy tariff times, and surplus energy back to the grid.

Insights tools and analysis platform: Advanced and instant qualitative and quantitative insights tools to collect occupant responses on comfort, health and wellbeing are to be developed integrating different expertise of engineering, architecture, psychology, physiology, etc. A web-based platform to visualize instant data collected will efficiently transfer building performance and occupant real demand to building stakeholders and provide recommendations for building service systems and human behaviours.

Sustainable technologies for advanced indoor environments: Intelligent buildings should be better featured by human-oriented built environment design and environment-friendly indoor climate technologies. When considering to improve human health and wellbeing, more sustainable technologies regarding energy efficient building design, low impact construction and ergonomic services should be identified and applied to provide advanced indoor climates achieving a higher sustainability performance.

3.3 Future Horizons

- Health, wellbeing and low energy use based indoor environment design will be tailored for different groups of end users regarding building typology, personal comfort profile and office "DNA". A holistic understanding of the factors existing in buildings and from the user perspective will be generated in depth to promote a knowledge evolution on the conceptual creation and strategic plan in future intelligent building development and construction.

- Human real demand to be fulfilled by reliably smart technologies and resilient indoor climates with "surplus energy" balance. Long-term monitoring of indoor environment as well as human behavior and occupant feedback gathering systems will be commonly embedded in the future buildings to fully access the real-time information and conduct artificial intelligence analysis with the big data collection.

- Maximize the benefits through social, environmental and economic dimensions when creating a living environment for humans. The added values of improved comfort, health and productivity will be further quantified and emphasized compared to the mere energy perspective in future buildings aiming for a better sustainability. New indicators and indices will be developed to sophisticatedly evaluate the performance of the next generation of intelligent buildings.

Chapter 3 aims to emphasise human health and wellbeing in indoor environments for future intelligent buildings along with low environmental impact and high economic performance over the whole building lifecycle. Quality of life makes contributions to the key performance indicators of social well-being and economic efficiency, and the specific visions of human health and well-being are one of the critical criterions in intelligent buildings' classification. Particularly in next-generation office buildings, user-oriented lower carbon footprint, and resilient office design solutions are to be implemented for future.

This chapter discusses the key features of human health and wellbeing in buildings as well as research gaps between the real perception from the user side and the measured building performance. Fundamental research questions are put forward that need to be answered. Research and development concerning knowledge, tools and technologies are initiated. Ultimately, new horizons for the future built an indoor environment of intelligent buildings are depicted.

The highlight of the conclusion is offering advanced indoor built environments for the future building users, which takes advantage of reliable and supportive technologies, and is rooted in evidence and resilient design thinking and human real demands. A circular design process instead of conventional linear design should be utilised to holistically integrate multidiscipline and diagnose the demand from users and stakeholders during the whole building lifecycle. Future R&D activities are needed as global database development, ICT embedded data collection, as well as sustainable technology implementation for advanced indoor environments. In a nutshell, we anchor three horizons: health, wellbeing and low energy use based indoor environment design, fulfil human real demand, as well as maximize benefits of living indoor through social, environmental and economic dimensions

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4. Technology Aware Workplaces

Matthew Marson

4.1 Introduction

Often, with intelligent buildings, it is found that lots of technology is implemented for the sake of technology – a demonstration of technical prowess. The vast majority of the systems implemented are for energy management. For knowledge-based industries, energy accounts for only 1% of the operation costs, yet real estate costs account for 9% and employees' salaries and benefits account for 90% (JLL, 2017). Therefore, human-centric design is, in fact, a more appropriate way to design use cases, select technologies and operate a building, helping businesses to achieve their wider outcomes.

Globally, workplace design is being increasingly important and relevant to business outcomes (Morgan, 2017). By being culture-centric, a business can demonstrate a key differentiator in a market of homogenised remuneration packages.

Noteworthy workplaces often feature fully integrated suites of technology. Having workplaces that are adapted in real-time, *using technology*, allows a business to reduce the productivity leakage of their workforce. Productivity leakage is the sum of all the pain-points that an employee experiences during the day that prevent them from doing something productive. This could include a faulty coffee machine, waiting for an elevator or voice-over IP technology that repeatedly fails. Sodexo believe that most white-collar workers experience around two hours of productivity leakage a day. For most businesses, this means that 25% of the working day is lost due to workplace inefficiencies. This represents a significant cost to the business. This paper will outline some examples across the below three value levers:

1. The Change Role of Technology in the Workplace
2. Wellness & Productivity
3. Social Collaboration & Space Optimisation

4.2 The changing roles of technology in the workplace

As robotic automation replaces the jobs of those doing repetitive tasks, the workforce of the future will be performing tasks that leverage non-automatable skills such as creativity, communication, innovation or collaboration. Often, workplaces are designed for a single person to sit at a single desk. This kind of design restricts fluid ways of working. The fundamental technology delivered in the workplace will become more consumer grade and more flexible and mobile than ever. Those working across geographies or from co-working or café spaces need enterprise technology that is as malleable as the expectations of a person performing a role.
The workplace is becoming more of a destination. IBM, the company that championed telecommuting for the vast majority of its history, is now recalling its staff to the office. The company believes that their employees need face-to-face interactions in order to develop their products and services, as well as be more engaged.

New methods of business such as a design thinking and agile development need different types of spaces and technologies. Design thinking requires collaboration

rooms for sticky note activities. Agile development needs ceremony space with audio-visual equipment that can demonstrate a software product. This means that the technology provided in the workplace needs to be integrated into the fabric of the building, in the fabric of the organisation and be well integrated to reduce support over-heads and productivity leakage.

4.3 Wellness & Productivity

The optimisation of the physical environment goes hand-in-hand with the productivity of the employees and their health and wellbeing (Stoddard, 2016). Delivering a technology empowered wellness programme to the workplace can help a business reduce its employee's sick days by 28% (ERS Research & Consultancy, 2016).

For example, by having a set of sensors linked to an Internet of Things (IoT) platform, it is possible to automate the control of internal air quality. In a meeting rooming, it is possible to observe the levels of CO_2 increase over time. When CO_2 levels in a space are too high, the ability to make decisions and to concentrate plummets (RESET air, 2016). By comparing the rate of CO_2 production with the occupancy (gathered from a mesh of quad-pyro passive infrared sensors) from a connected lighting system and the design values of the space, machine learning can be applied to control the volume of fresh air being delivered to that space. This way, the building can autonomously keep the internal air quality as healthy and productive as possible.

The industry is also seeing the growth in demand for circadian lighting. Circadian lighting has two main types. The first type 'daylight harvests'. This means that it only adds synthetic light in addition to what natural light is not providing. The driver for colour temperature is still the sun. The second type of circadian lighting synthetically controls the colour temperature to mimic the sun. Both have been shown to be far less disruptive on a person's circadian rhythms. Technology can also be implemented on occupant's laptops and phones that make the back light of the device follow the circadian rhythm. This means that the employee is able to get to sleep naturally and is therefore more productive the following day. This use case combined both energy efficiency and health for the business imperative.

Productivity leakage can also occur through the lack of availability in concierge-type services. The ability to ask simple questions with an emotional touch helps employees to be more effective when dealing with organisational policy. Today, we are seeing customer services organisations implement artificial intelligence chatbots to deal with high customer demand. This significantly reduces the operational overhead whilst delivering a sentiment-based response. Fjord believes that artificial intelligence will be the user interface of choice in the future. By implementing this kind of technology in a building, employees will be able to adjust room settings, find available spaces on the fly, check the status of requests and much more. We will the growth in the concept of building service user interface in line with consumer liquid expectations.

Beyond voice, video will also be used to measure the sentiment of employees. Linking a series of cameras to a video analytics platform will analyse the facial expression and postures of employees to understand their mood. This means that the building can intelligently adapt the surroundings to increase comfort. Perhaps when it looks like someone is having a bad, the building could reward them with an increase. These sorts of

ludic or delight events inspire employees and keep them engaged.

4.4 Social Collaborations & Space Optimisation

The management of space can often cause dissatisfaction in the workplace. The ability for employees to query real-time utilisation data, means that they can make decisions on where to go for some focused time, or a private call. They can also make an intelligent decision on when it is good to go to the canteen. Being able to expose this data in a user-friendly way is often a challenge for real-estate departments.

Knowledge workers rely on the knowledge of others. In large organisations, the ability to connect and speak to others is often achieved through social knowledge as corporate directories are often hard to navigate and do not relate to the physical world. Implementing a set of location services in a building allows a culture of collaboration to be achieved. Today, if you need to find someone with analytics skills for the project that you're working on requires you to email someone that may know someone. Before you know it, you have been passed through tens of connections. By integrating the location of employees (through WiFi triangulation or a Bluetooth beacon enabled mobile app) to a skills database, means that colleagues can now connect faster with those in the same building. This reduces productivity leakage and increases interdisciplinary interaction. For businesses wishing to be more innovative, the building can force social collisions by displaying interesting information about those in the immediate vicinity to start a conversation.

This sort of technology often creates privacy concerns. By ensuring that the employee has to opt-in into different levels of privacy, means they are more forthcoming with the vision. By limiting the display of data to back-end, the front-end, then biometric systems, employees are able to expose as much or as little data as they are comfortable with. The ability to switch on and off on demand is an import control that makes the populous feel more comfortable.

Location services can also be leveraged to reduce productivity leakage by giving the ability for employees to rapidly find a thing (such as a high-value or well-used piece of equipment). This allows an organisation to make better use of scarce resources and maintain assets properly. It also allows individuals turn-by-turn navigation to parts of the building that they are unfamiliar with. This helps visitors and temporary employees get their bearing within a building.

4.5 Summary

The clear majority of the use cases above can only be achieved through comprehensive integration of legacy and additional systems throughout the building.

Traditional building management systems are not sophisticated enough to deal with the number of integrations, or computations. Having a connection to a cloud-based IoT platform, means that buildings can have new applications installed to unlock enhanced automation or other use cases.
As the line between the physical and the digital continues to blur, we will see the increase in technology in the workplace.

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5. Daylight in Intelligent Sustainable Architecture

Juergen Koch

5.1 In general - Daylight and its Importance:

Daylight is the basis of all life and growth. It controls our organism and has a significant influence on our health, performance and well-being. Daylight serves not only to see, but gives us spatial orientation, orientation to the time of day and season because orientation is essential for our well-being as well.

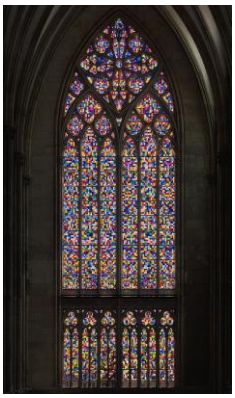
Being without orientation is a terrible condition that can be caused by illness or is generated by external circumstances for that architects and engineers sometimes are responsible for. The sun can be used for heating our buildings as well.
Winter gardens or roof glazed atriums are excellent examples as so called climate puffers.

Daylight is, however, also the most natural free resource.
Why we don't use it more intelligent in architecture is incomprehensible and irresponsible.

5.2 "Daylight cannot be replaced by anything"

How do we use daylight in commercial architecture today?
What is the "status quo"?





Historic Daylight Architecture - Cologne Cathedral

Seagram Building New York City 1958

Architects and inhabitants has always the dream of buildings having a clear and wide view into the environment and nature and at the same time being protected from the elements. With the development of even better and larger glazing's, this dream came true after World War II since the middle of the last century. The famous architect Mies van der Rohe was one of the protagonists in "Bauhaus" architecture and masters of reduction to the essentials. The Seagram Building (1958) in New York City is one of the most famous skyscrapers representing this dream. But Gothic cathedrals show the fascination of daylight and large glazing's as well centuries ago.
More daylight in architecture was the reaction to the narrow, dark and unhealthy housing conditions that with the first industrial revolution led to inhuman conditions in rapidly growing industrial cities.

With large glass surfaces are not only benefits came up. Direct solar irradiation over large glass surfaces also leads to glare of the occupants and to overheating the interiors. Internal glare protection and air-conditioning systems have to heal the deficiencies of our buildings with a huge energy input.
By the mid-seventies of the last century, oil was cheap and no one was looking for more intelligent solutions. Glass industry and refrigeration industry became very good friends from that times.

In many commercial buildings the cost of HVAC rose to 40% of the total construction costs. Despite these problems, large-scale glazed buildings have not lost their fascination to this days. „The dream is still awake.“ But we have to solve the problems so that the dream does not become a nightmare.

It was first the oil crisis in 1972 and the publication of the Club of Rome report,
"The Limits of Growth," which led to a trend reversal.

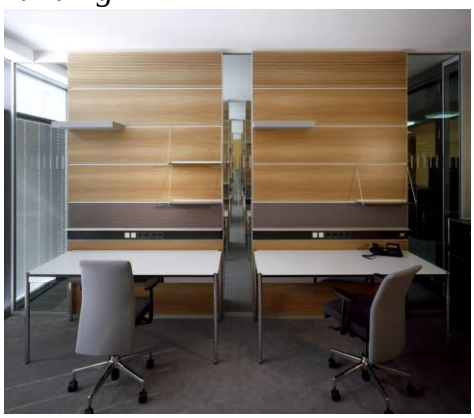
Initially, architectural concepts were developed in housing construction, which attempted to make climate-friendly residential buildings with passive natural resources. Winter gardens, which captured the heat of the sun for heating purposes, became modern again. But in commercial buildings, little has changed as far as the intelligent use of sunlight is concerned. So far, we have come up with no better idea than shielding the glare and turning on the artificial light when the sun is shining. With some luck, the caretaker turns off the lights at night. In many commercial buildings artificial light burns all night until morning. This is absolute nonsense and is the opposite of intelligent buildings.

So the answer to the question how we use daylight in commercial architecture is:

We use it just a little and that in a stupid way. This is totally crazy and quite primitive compared to the automotive industry for example or the digitalised world in other areas. The internal sun protection/blinds can only be used as glare protection. The solar heat still reaches the rooms and causes cooling. That means, sunlight causes energy need. It should be exactly the other way around.
It is time to use sun and daylight more intelligent for our buildings and cities7public areas.

Daylight Architecture is one of the most intelligent ways to use free renewable energy and increase comfort, health and well-being in our buildings and by the same time reducing carbon emission.

"Spherion" Deloitte's German Green Corporate Daylight Architecture - Best Office & Office of the Year 2014-Green Building


5.3 What can be done better to use the sun and daylight more intelligent?

Using daylight and the sun more intelligently not only means better light quality, health, comfort and well-being for the user, but also a reduction in heating and cooling requirements and the associated waste of energy and at the same time reducing CO_2 emissions.

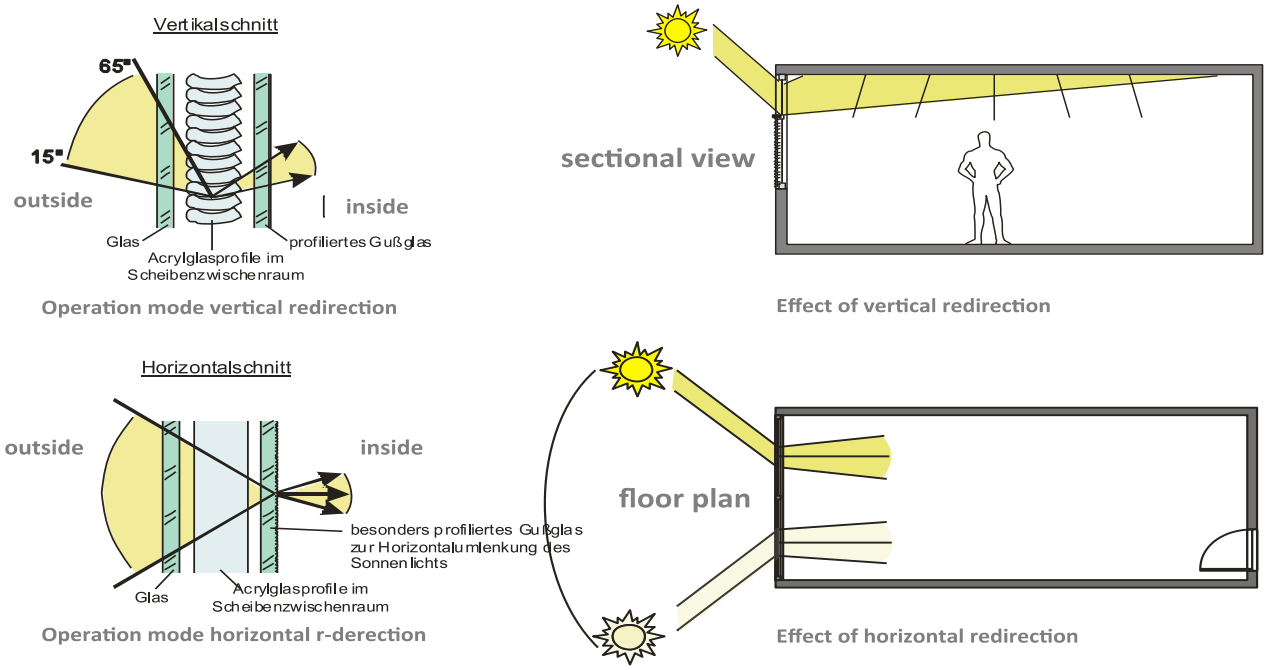
We have to control the daylight in a better way so that less heat enters the interior. Integrated blinds in between of triple glazing can, for example, be a good solution. However, since daylight is not constant, but constantly changing, intelligent buildings must react to it automatically. By the same time the blinds are closed a part of the daylight reaching the window should be used intelligent. This means that modern facades and conservatories should respond to weather conditions, sun exposure and intensity and changes in the use of the building.

The components are:

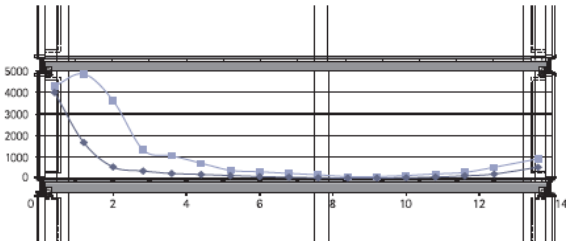
1. Daylight redirection elements.
2. Efficient electrical sun- and glare protection system.
3. Control system which regulates the sun protection system automatically.
4. Sensor-controlled LED lighting, which reacts automatically on the daylight offer.
5. One or two weather stations on the roof of the building.
6. A clever person who writes the program for the control system.

To control the blinds a program has to be written that is adapted to the building, its use and its natural and social environment.

This system is not really complicated, but it is complex. It reduces the power requirement for lighting up to 25%. At the same time it ensures that less cooling and heating is required. This means, of course, that the control system must be connected to the overall building control system as well. The areas that are supplied with natural healthy daylight can be doubled. In this case, improving comfort, well-being and health of employees means that the productivity of employees in these buildings is much better.



Daylight redirection combined with sensor-controlled lighting



lux - lower line without redirection, traditional shading with innovative daylight above line is with redirection

daylight redirection with closed blinds daylight redirection with open blinds

5.4 Conclusion:

Why we do not more of these? Are there industrial interests blocking new technologies?
To design und realise more intelligent green and sustainable buildings does not mean to put on something on traditional construction methods and systems to make them more expensive, it is about to change something in the process of planning and to integrate and cultivate new technologies in our architectural design language. It is called IED, Integrated Energy Design. That means for example, the quality and functions of façades are becoming of more importance and connected holistic systems are required instead of the traditional addition of separate systems. But it also means, that the money for construction is moving from the old technical centres into the outer skin of sustainable intelligent buildings.

In commercial buildings of course are other and additional ways of using daylight than in facades are recommended, like roof lights. But that means for example for supermarkets, to control the incoming light as well but in a generally similar way as in facades.

It is all about connecting and combining different systems to control the daylight in our buildings and our buildings must be able to react on changing weather- and use conditions. The panning instruments have to consider different dynamic processes over the year, so we use dynamic simulation programs optimising the relationship between buildings and the changing environment conditions, like in a living organism.
The dimensioning of technical aggregates, based on worst case conditions, is of the past.
It is about optimisation and using synergies to get more intelligent buildings.

Worldwide 1st new generation of daylight and carbon neutral Supermarket in Berlin

But one thing always has to be considered first, people. People should always be in the focus of everything that architects and engineers do. It's not about what's technically possible. We need to be careful not to get over-engineered buildings, we need robust and resilient solutions because human habits in building use are different and are not a constant factor in all engineering calculations, as the computational models often suggest.
Buildings and their technical systems need to be intelligent, but also easy to handle.

Daylight Architecture is one of the most intelligent ways to use free renewable energy and increase comfort, health, well-being in our buildings and reduces carbon emissions, hopefully soon.

We have to use daylight in commercial buildings more intelligent by controlling the daylight so that less heat enters the interior. Daylight redirection combined with integrated blinds in between of triple glazing, for example, is a good solution. However, since daylight is not constant, but constantly changing, intelligent buildings should react to it automatically, like in a living organism.

That does not mean to put on something on traditional constructions to make them more expensive. It`s about to change the planning process, to integrate new technologies into our architectural design and using synergies. It’s called IED, Integrated Energy Design.
The quality, complexity and functions of facades are becoming more important and connected holistic systems are required to control the daylight, artificial light, heating, cooling and ventilation. Dynamic simulation programs can help to optimise the relationship between buildings and the environment.

But one thing has to be considered first, people should always be in focus of everything that architects and engineers do. It's not about what's technically possible.
Around the country we need better legal regulations regarding minimum distances between buildings related to their height, so that architects and engineers get the chance to use the sun more intelligent for well-being.

We also have to be careful not to get over-engineered buildings, we need robust and resilient solutions because human habits are not a constant factor in engineering calculations, as computational models often suggest. Buildings need to be intelligent, but also easy to handle.

Controlled daylight use in buildings is one of the most intelligent ways to use free renewable energy and increase comfort, health, well-being in our buildings and reduces carbon emissions, hopefully soon.

6. Intelligent Infrastructure

Mark Worall

6.1 Conceptual framework:

Buildings are one of the priority areas for tackling urbanisation issues through smart city initiatives (Airaksinen, *et al*, 2016). Intelligent buildings will play major roles in tackling energy, resource and environmental issues and the intelligent buildings roadmap will set out many of the challenges facing the sector, but also opportunities for advancement. However, intelligent buildings developed in isolation will not be able to fully address the challenges and will therefore not in of themselves provide optimal solutions.

Figure 6.1. Buildings, the city and its infrastructure

Buildings are a part of a complex ecosystem that displays many of the features of living organisms (Nilon, *et al*, 2003) – flows of energy and matter, flows of information, interaction with the environment, rhythm, growth and decline and evolution. Historically, buildings and the infrastructure connecting it to other buildings and services have had no interaction apart from such one way processes such as metering and billing.

If buildings are seen not as individual entities, but as dynamic components in that ecosystem, then "intelligent infrastructure" should be considered as the distribution system connecting individual intelligent buildings in a multi-faceted, interactive network.

Infrastructure connects buildings to the wider community through networks that have functions as diverse as the supply of services such as electricity, fuel, water and communications, the removal and treatment of waste such as sewage and refuse, and the movement of commuters through road and rail networks.

Buildings have a wide variety of uses, ranging from residential dwellings, office and commercial buildings, retail, catering and leisure centres, public buildings such as schools and hospitals, factories, warehouses and distribution centres and data centres and server buildings. The wide

range of services networking with buildings and the diverse range of building type and usage pattern means that intelligent infrastructure can allow individual buildings to operate whilst the infrastructure enables the system as a whole to be optimised.

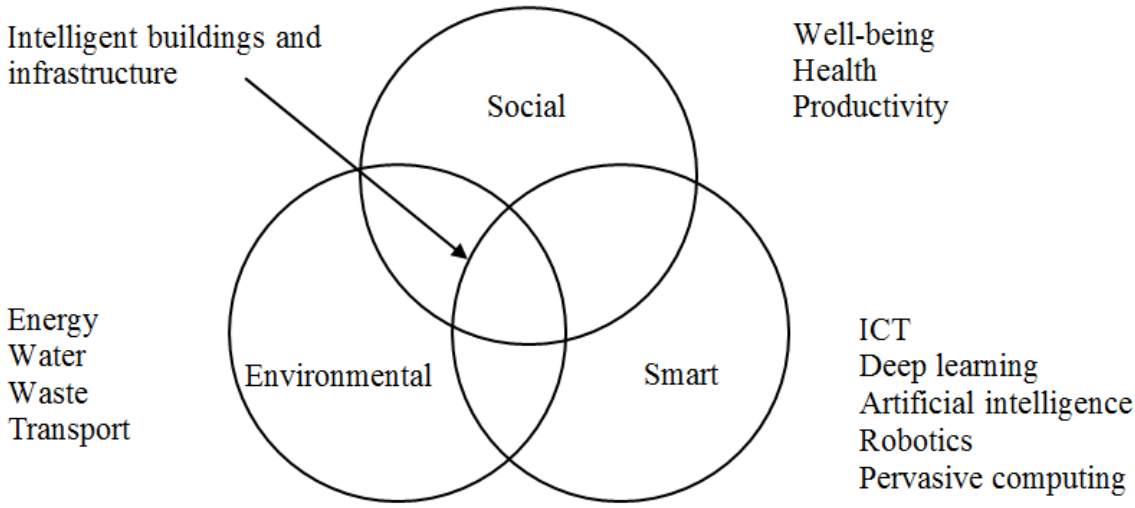


Figure 6.2. Diagram indicating the interrelationship between social, environmental and smart elements that defines intelligent buildings and infrastructure.

Intelligent buildings and infrastructure enables buildings to be productive and cost-effective environment based on three basic intersecting elements;

- social
- smart
- environmental

Social

We spend over 80% of our time in buildings (Klepeis *et al*, 2001) and the needs and desires of people manifests itself in demand for services and consumption of resources. Developing intelligent buildings and infrastructure that respond the people's needs will contribute to well-being whilst addressing the capacity of the environment to meet these needs in more sustainable ways.

Smart

Infrastructure is becoming connected through advances in information and communication technologies (ICT). Internet connected sensors and devices are becoming more and more available and it is projected that there will be over 26 billion connected devices by 2020 (Evans, 2011). Recent advances in areas such as complexity modelling, data mining, deep learning, AI, and the internet of things (IoT) could enhance the drive to more efficient use of resources and the optimisation of buildings and the infrastructure serving the needs of people. These developments present many challenges, but also opportunities for advancement (El-hawary, 2014).

Environmental

Buildings use up to 40% of the world's energy resources, around a third of carbon dioxide emissions and 10% of water withdrawals, so the provision of electrical power, heat, water and waste are important for developing sustainable building services. Until recently there has been a one way relationship; energy and water was delivered and waste was removed; but the advent of smart grids and intelligent networks is meaning that the management of resources is becoming more dynamic and responsive. Two of the main services vital to buildings and the people using them are energy and water. Energy and water are inextricably linked. Water is necessary for power

generation and energy production and energy is needed for water extraction, processing and delivery and this interconnectedness is sometimes referred to as the water-energy nexus. Intelligent infrastructure will integrate the production and distribution of energy and the provision of water and waste services.

6.2 State of the Art

Social infrastructure
Challenges

- *Health*: As urban population density and GDP increases, energy consumption, water demand and transport use will increase. The health, safety and well-being of people, especially vulnerable sections of society such as children, the elderly and people with underlying health conditions will be harmed due to increases in pollution, emissions and inadequate sanitation. The infrastructure connecting buildings to its services will need to balance the demand for services with the needs of people for good health.
- *Wellbeing:* The WHO states: 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'. The term 'well-being' reflects one's feelings about oneself in relation to the world. Many issues contribute to health and wellbeing either positively or negatively, and intelligent infrastructure can contribute to good outcomes and mitigate poor outcomes.
- *Employment:* Intelligent buildings as workplaces, provide environments in which people perform tasks in a productive and cost effective manner, but in which their well-being is not just an afterthought, but is part of the process. However, the development of automation, robotics and artificial intelligence (AI) could see the loss of jobs over a wide range of occupations. Frey and Osborne (2017) predict that up to a half of total US employment is at high risk of being replaced by computerisation and automation.
- *Job losses*: Buildings designed to support sectors vulnerable to computerisation (low skilled, low wage sectors) would be surplus to requirements and would need to be modified in order to cater for newer job categories, converted to other uses, left unoccupied or be demolished. This would present challenges to;
    - The owners of buildings, due to the loss of revenues over a building's lifetime, costs of conversion to new use, or costs of demolition and rebuild.
    - The users of building in emerging job categories, should buildings not be fit for purpose, which could lead to frustration, reduced job satisfaction and lower productivity.
    - Architects and urban designers, due to the need to refurbish existing buildings or creating new buildings suitable for emerging job categories.
    - The urban landscape, as cities are transformed (in either planned or unplanned ways) due to the modification of existing buildings, the creation of new buildings or the abandonment/demolition of obsolete buildings.
- *Fragmentation*: If alternative employment or new job categories do not emerge to replace the ones lost to computerisation or adequate re-training (social infrastructure) is not made available, then society could fragment into sections that have the skills and capital to exploit the new technologies and those that do not.
- *Urbanisation:* Well-being is a complex concept that includes job satisfaction, a good work-life balance, stimulation of the mind, interaction with nature, health, wealth and happiness. As urbanisation increases due to economic and population growth and the stresses of living and working in cities rises, individual and societal well-being is in danger of being undermined.

- *Green spaces*: as infrastructure develops to meet the needs of cities, natural spaces, such as parks, gardens and playing fields are in danger of being lost to buildings, roads and pavements. A positive relationship between green outdoor spaces and levels of stress in the workplace has been found (Lottrup *et al* 2013). The well-being of the occupants of buildings will suffer with a decline in natural spaces. This will result in reduced performance at work, increased signs of ill-health, such as absence from work, an increase in sickness levels, reduced retention rates for good staff and a higher turnover. This will have an adverse economic effect to employers, who will have to compensate for reduced productivity and output.

Opportunities

- *Adaptability:* Intelligent buildings should be designed to be adaptable and reconfigurable, so that they can meet the challenges of changing work patterns, but intelligent infrastructure presents important opportunities for bridging the gap. For instance, heat networks can provide thermal energy to buildings, but if the energy usage changes with work patterns, then adjustments can be made at the infrastructure level, saving investment costs in individual building HVAC plant.
- *Better jobs:* Many of the repetitive, tedious, physical and mentally stressful jobs currently carried out by people will be computerised, enabling many to pursue more interesting careers, thus enhancing personal well-being.
- *New jobs:* New employment opportunities will be created by computerisation, which may more than offset the jobs lost.
- *Economic growth*: cities are engines of economic growth (80% of global GDP) due to the concentration of diverse pools of labour and the ability of people and businesses to share information and knowledge (UN DESA, 2015).
- *Economies of scale*: investment in physical (roads, pipelines, cables) and social infrastructure (education and health) is more effective in cities than in rural areas due to economies of scale (UN DESA, 2015).
- *Green spaces*: as infrastructure develops to meet the needs of cities, natural spaces, such as parks, gardens and playing fields are in danger of being lost to buildings, roads and pavements. A positive relationship between green outdoor spaces and levels of stress in the workplace has been found (Lottrup *et al* 2013). The well-being of the occupants of buildings will suffer with a decline in natural spaces. This will result in reduced performance at work, increased signs of ill-health, such as absence from work, an increase in sickness levels, reduced retention rates for good staff and a higher turnover. This will have an adverse economic effect to employers, who will have to compensate for reduced productivity and output.
- *Health*: As urban population density and GDP increases, energy consumption, water demand and transport use will increase. The health, safety and well-being of people, especially vulnerable sections of society such as children, the elderly and people with underlying health conditions will be harmed due to increases in pollution, emissions and inadequate sanitation. The infrastructure connecting buildings to its services will need to balance the demand for services with the needs of people for good health.
- *Commuting*: Computerisation may reduce the need for commuting as more people may be able to and be happy to work from home or in non-office environments.

Smart infrastructure
Challenges

- *Security concerns:* vast quantities of data are shared between buildings and networks, so systems are vulnerable to cyber-attack. Encryption and other security measures ensure that most transactions are safe and secure, but weak points can be exploited that allow access to sensitive data and leaving individuals or organisations vulnerable to attack. Financial resources, intellectual property and organisational security can be compromised.
- *High initial costs:* infrastructure requires physical (or virtual) connections between buildings, networks and suppliers, so costs of installation in laying cables, pipework and ducting may be substantial.
- *Fear of obsolescence:* information technology and smart devices are developed rapidly, but often superseded or upgraded in relatively short periods of time. Therefore, there are fears that investment in "intelligent infrastructure" or other "smart" technologies may be a waste of money as the technologies become obsolete.
- *Disconnect between user and the technology:* pervasive computing, in which user friendly interfaces, such as voice recognition software and virtual assistants, are removing the barriers between users and services to produce a seamless, intuitive environment. As users become less familiar with the way that the underlying technology is operating, they will be less aware of potential problems. Users will then be relying on regulating authorities or experts to hold the technology operators to account.
- *Interoperability:* vast volumes of data are processed from a wide variety of sources, with different software and communication protocols. If sources and networks cannot communicate, then AI will be less effective. Many organisations at the forefront of AI development use proprietary systems that are not interoperable with other systems.
- *Privacy:* as data are constantly being generated and analysed from intelligent buildings, intelligent infrastructure and the people that use them, there are many concerns that personal and organisational information that is currently protected by privacy laws will be available to third parties, whether they be employers, governments, political organisations, advertisers or criminals. If individuals or organisations do not have confidence that the data generated will be used responsibly, then there will be resistance to the take up of smart devices, which in turn will reduce the effectiveness of the system.
- *Personalised services:* AI and data analytics now have the ability to create personal profiles from the data generated, which can help companies to target advertising to specific groups and provide information on political and social interests to lobbyists and polling organisations. Many of the services provided are useful and benign, but many could infringe on people's right to privacy. Balancing the right of data analytics organisations to masses of data and the right of an individual or an organisation to privacy is a vitally important challenge.
- *Disruption:* Internet enabled sensors and devices are becoming part of the ICT ecosystem. These devices are increasingly being used to facilitate distributed denial of service (DDoS) attacks, in which malicious actors flood a target with service requests to overload the system in order to disrupt or to extort. Many of the devices in the near future will be wireless micro-devices embedded in infrastructure, with minimal security protection, so as the networks expand they will be more vulnerable to attack.

Opportunities

- *Efficiency:* intelligent distribution and use of resources through ICT, AI and complexity modelling will enhance the efficiency of systems, make better use of existing infrastructure and reduce the need for additional infrastructure.
- *Flexibility:* data mining and deep learning at an infrastructure level enable AI to predict supplies and demands and respond quickly to any variations. This is especially important as more renewable energy supplies become part of the supply mix or buildings become energy producers as well as consumers.
- *Transparency:* intelligent infrastructure, such as smart grids, involves two way flows of communication between buildings and the network. Users can monitor resource use and modify behaviour to reduce consumption or save money and suppliers can monitor usage and modify tariffs or incentives to better manage resource use.
- *High quality:* networks take the strain of peaks and troughs in demand of both consumer and supplier.
- *Resilience:* intelligent infrastructure can take the strain during extreme events.
- *Environmentally friendly:* intelligent energy infrastructure (electrical energy and heat) allows us to manage a wide variety of primary energy sources. If we want to reduce carbon emissions and increase the utilisation of renewable energy, then the infrastructure will enable us to meet these objectives.

Environmental infrastructure

Energy

Challenges

- *Building energy consumption*: as the number of buildings increases with population and economic growth, electrical energy demand will grow, which will cause high power system loading on existing infrastructure and result in overstressed equipment.
- *Thermal demand*: approximately 50% of a building's energy use (Ürge-Vorsatz, *et al*, 2015) is from thermal demand, such as for space heating, cooling and hot water provision. The majority is provided by fossil fuels such as coal, natural gas and oil. In developing countries of South East Asia, cooling demand at present is up to 70% of total thermal demand and consumption will increase significantly as cities expand. As people become wealthier, they will demand modern facilities such as air conditioning.
- *New consumers*: demand will increase not just due to the increase in the urban population, but because of technological advances in such areas as transportation (electric vehicles and urban public transport), data handling (telecommunication hubs, data centres and server buildings), and robotics (automation of tasks currently carried out by people).
- *Urban heat island effect*: the growth of cities and an increasing population density will cause ambient temperatures in cities to increase in comparison to the surrounding areas (the heat island effect). Even without factoring in increasing temperatures due to global warming, there will be increasing instances of heat waves, which can cause heat exhaustion and heat stroke, leading to an increase in illness and mortality in vulnerable sections of society. Building energy consumption will increase to counteract the heat island effect due to the demand for building air conditioning, which will result in overloading of the electrical network. Current practice is to bring on low efficiency, highly polluting stand-by plants and ration supplies (rolling power cuts, charges to discourage use, incentives to encourage use at off-peak times) at peak times or during heat waves.
- *Renewables*: Figure 4 shows the share of global demand met by renewables at present and by 2040 in the new policies and the 450 scenarios (IEA, 2016a). As renewable energy increases in capacity and share of global demand, the infrastructure will need to be able to manage the intermittent and fluctuating output.

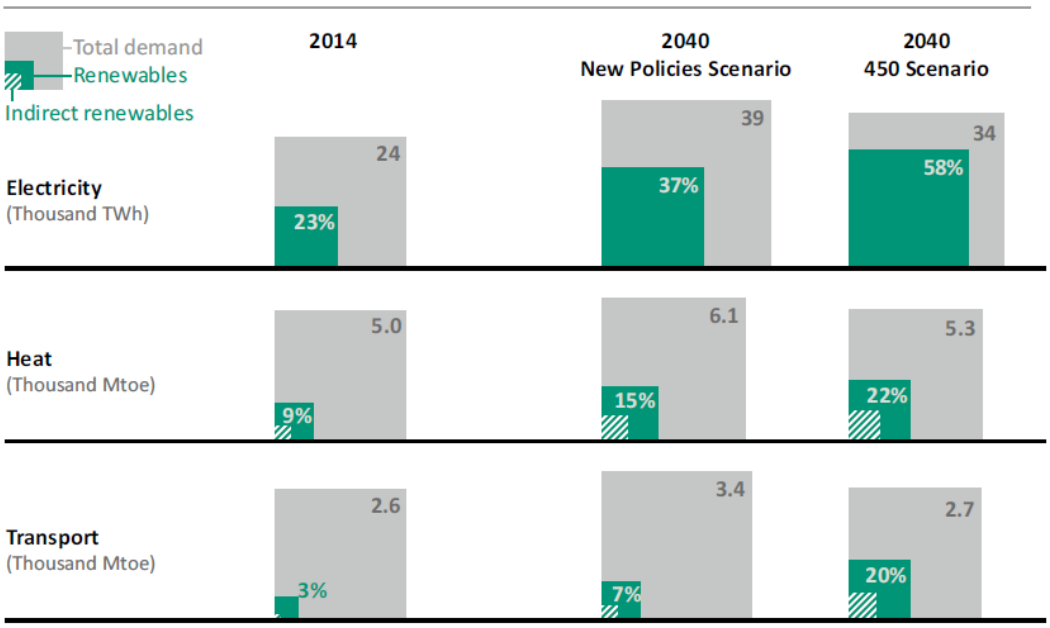


Figure 6.4. Share of global demand met by renewables in selected sectors in new policies and 450 scenarios (IEA, 2016a).

- *Micro-generation (<50kW)*: buildings will increasingly be electrical generators as well as users, though expansion of micro-generation systems such as solar photovoltaics, wind turbines, combined heat and power (CHP) and micro-CHP systems. The network will need to be able to manage the variable nature of supply and demand between individual buildings and the infrastructure.

Opportunities

- *Building consumption*: innovations in intelligent building technologies are reducing electrical energy consumption in traditional areas such as lighting and high performance glazing and facades, but most buildings consume more energy than predicted, therefore there are opportunities to reduce energy consumption further by improved prediction and control. Complexity modelling and deep learning are emerging technologies that involve data mining, analysis, forecasting and prediction using AI algorithms. The data mining will not be limited to the analysis of individual buildings, but will encompass the gathering of a wide variety of information from different parts of the infrastructure connecting the building, its occupants and its surroundings.
- *Thermal demand*: In 2008 heat losses of the EU27 energy system before end use were 39.3EJ, around 19EJ were from electricity generating power stations and so were not recoverable, but the remainder (29EJ) was considerably more than the demand of around 11 EJ (Andrews, *et al*, 2012). In large urban conurbations and cities, district heating and cooling (DHC) could play a major role in increasing energy efficiency, by using waste heat from electrical power generation plants and waste incinerators for thermal demand, utilising low grade heat sources that would otherwise be wasted (industrial processes), utilising renewable and low carbon heat (solar thermal, biomass, geothermal), reducing the need for electrically powered cold thermal demand (compression chillers) by using heat driven absorption chillers, heat pumps and free cooling (rivers, sea water, aquifers). DHC infrastructure usually includes means of thermal storage, and so peaks and troughs of demand from buildings can be managed within the DHC network. AI can be used in DHC networks to optimise the performance of individual buildings and the overall network.

- *New consumers*: Electric vehicles such as cars and buses will require additional electricity capacity, but could be used as short term electricity storage systems in buildings. Intelligent infrastructure requires more storage capacity to manage supply and demand and so electric vehicles could help to manage the system. Data centres are emerging as major electrical energy consumers and carbon dioxide emitters due to the need for cooling. Developments in low temperature DHC will enable the low grade heat generated from data centres to be used, whilst at the same time reducing electrical energy demand.
- *Urban heat island*: Intelligent buildings could play a role in tackling the problems, such as developing green roofs, facades and building envelopes that selectively absorb/reflect solar radiation to reduce the effect, but buildings themselves could not solve the problem. It will require the infrastructure of the city or district to be modified, so that there is a balance between highly absorptive structures such as buildings, roads and pavements and green spaces, heat refuges and shelters.
- *Renewables*: renewable energy systems requires intelligent infrastructure that can accept the intermittent and variable nature of the output and a robust and resilient network to manage the flows. As renewable energy generation grows from a small contribution to dominating the energy supplies, intelligent infrastructure will need to develop innovative energy storage systems. Energy storage could take the form of electrical (batteries) thermal (hot water or ice), mechanical (flywheels/compressed air), chemical (salt hydrates) or electro-chemical (batteries/ fuel cells).
- *Micro-generation*: Buildings with integrated renewable energy systems will increasingly be developed in the coming years, and there are many advantages to generating renewable electricity and heat at a building level. Solar and wind act on buildings whether we utilise the energy or not, so it makes sense to extract some of the energy if it is practically and economically feasible to do so. Buildings can reduce their utility bills, or can gain a revenue stream by selling any excess. Management of the fluctuating and variable supplies will be challenging to the electrical network, and so energy storage will need to be integrated into the electricity infrastructure.

Water
Challenges

- *Demand:* A large share of the water (up to 90%) withdrawn by households and services in high per capita use areas (developed countries such as the North America and Europe) is returned as wastewater, which requires treatment and energy consumption. The majority of water withdrawn in the municipal sector is for non-personal use, such as flushing toilets, washing dishes and clothes, watering lawns and washing cars (Cosgrove and Rijsberman, 2000).
- *Urbanisation:* Urbanisation is projected to grow from one-third urban in 1950 to two-thirds urban in 2050 (UN DESA, 2015). The water/energy infrastructure will need to be maintained and expanded to meet the growth in demand for clean water and the provision of sanitation.
- *Environment:* All uses of water cause some level of pollution, which needs to be treated before it can be reused. Less than 100% of pollutants are removed because of prohibitive costs, so some remain in the water or accumulate in the soil. In developing countries, the provision of sanitation is not keeping up with population growth, resulting in increases in pollution of water and the aquatic environment.
- *Health:* If water services do not keep up with demand in rapidly expanding urban areas, then this will lead to an increase in water-related diseases and deaths (3.4 million deaths due to waterborne diseases in 1998 (WHO, 1999)).

- *Unplanned development:* Rapid and unplanned urbanisation in developing countries has led to the expansion of slums or informal settlements (one third of all urban residents in developing countries live in informal settlements (UN DESA, 2015), and will continue to pose health risks and impede the life chances of people due to the lack of access to clean water and sanitation.
- *Conflict:* Transboundary river basins account for around 60% of all freshwater flow and supplies around 40% of the world's population (IEA, 2016b). Management and use from one location can affect downstream locations, thus creating potential tensions between states.

Opportunities

- *Energy efficiency:* Increases in the efficiency of energy production and power generation systems will reduce withdrawals and demand for water. This in turn will reduce the need for water treatment. CHP and waste heat recovery systems linked though DHC networks can also improve the efficiency of the power and heat supply infrastructure.
- *Waste-water recovery:* Energy recovery from wastewater could provide opportunities to improve the efficiency of the water treatment process.
- *Embodied energy:* There are opportunities to exploit the embodied energy in waste-water by generating electricity from biogas.

6.3 Future scenarios

Energy

Global economic growth is set to more than double over the next 20 years and energy demand and CO_2 emissions are set to increase alongside. Figure 3 (IEA, 2016a) shows the trends in three scenarios, current policies, new policies (taking account of broad policy commitments and plans that have been announced by countries) and 450 scenario policies (an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO_2). In new policies scenarios, energy demand CO_2 emissions are still set to increase and in the 450 scenario, energy demand is projected to flatten out and CO_2 emissions are set to decrease.

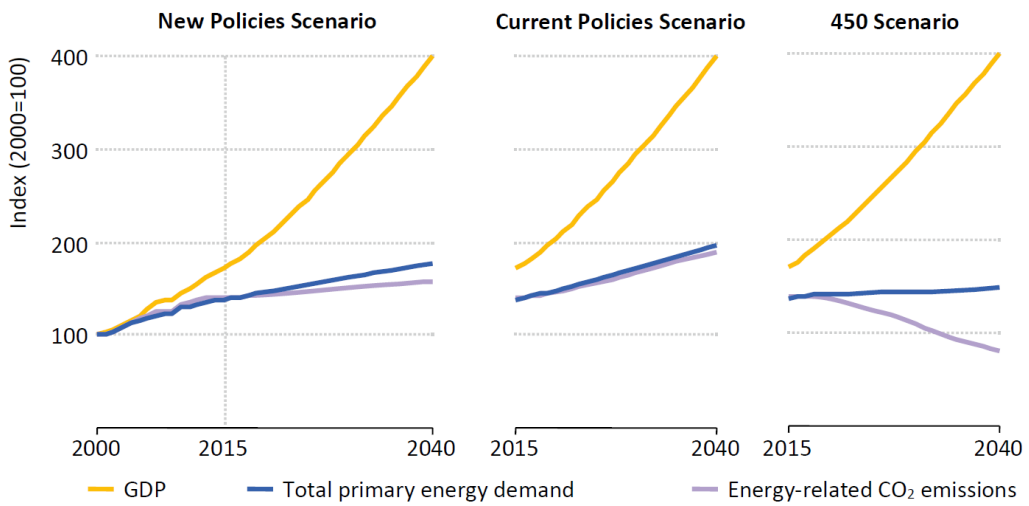


Figure 6.3. Global GDP, energy demand and CO_2 emissions trajectories by scenario (IEA, 2016a).

Buildings are responsible for over 40% of energy consumption and 33% of carbon dioxide emissions (IEA, 2016a). As over half of the population of the planet now live in cities (UN DESA, 2015), and cities become more densely populated, meeting the demand of a growing and wealthier

population requires drastic action to mitigate and reduce the effect on the environment and resources and to better utilise renewable and low carbon resources.

Water

Water is an abundant resource, but only about 2.5% of it is freshwater. Of that, less than 1% is available for human use, as almost 70% is held in glaciers and ice, and roughly 30 % is deep underground or unsuitable for human consumption. Most of the supply is from surface water and groundwater sources, with global freshwater withdrawals increasing by around 1% per year since the 1980s. The withdrawal rate is outpacing the recharge rates by 1-2% per year globally, therefore groundwater sources are diminishing and becoming more vulnerable to seawater intrusion. Agriculture is the main cause of withdrawals and water consumption. The municipal sector accounts for 13% of withdrawals and 5% of consumption, the energy sector (power generation and primary energy production) accounts for 10% of withdrawals and 3% of consumption, whilst the industrial sector accounts for 12% of withdrawals and 8% of consumption. It is projected that withdrawals to meet municipal demand will increase 17% by 2040, withdrawals to meet industrial demand are projected to remain approximately the same (8-9%), and withdrawals in the energy sector are expected to rise by around 2% by 2040, but consumption is expected to rise by almost 60% (IEA, 2016b).

6.4 Development strategy

The development strategy for both intelligent buildings and the intelligent infrastructure that serves them should aim to integrate the social, the smart and the environmental aspects holistically. Concentrating on one aspect at the neglect of others may deliver some positive outcomes, but will not provide modern, efficient, cost effective, profitable, sustainable and pleasant environments in which people live and work.

Specific topics for consideration.

Well-being

Most buildings are designed to be occupied by human beings, but well-being is often low on the priority list, if considered at all. Well-being can be enhanced though the design of a space, and the consideration of human physiology and physiology, but if occupations are stressful or unfulfilling then well-being can be seriously undermined. There will always be occupations that can undermine well-being, and stressful or unfulfilling jobs will always be with us, but intelligent social infrastructure can create urban spaces that mitigate some of the negative effects and make work more productive.

Hard and soft infrastructure

A balance must be found between hard and soft infrastructure. We define hard infrastructure as that which consists of concrete, glass and steel buildings, roads, pavements, plazas, and soft infrastructure as that which consists of parks, gardens, wildlife corridors, green roofs, water features.

A concentration on hard infrastructure contributes to overheating of cities in summer, which leads to higher energy consumption, an increase in pollution and carbon emissions, and impacts on human health and mortality. From an environmental point of view, soft infrastructure provides shelters from heat and cool spots, it can reduce the overall heat island effect, it also absorbs carbon dioxide and releases oxygen and water vapour into the atmosphere. It is now widely recognised that people respond positively to a connection with nature, whether that is for leisure or work, so that health and well-being can be enhanced (assuming that work-life balance and satisfaction can be achieved), improving motivation and productivity, whilst reducing costs.

A balance between hard and soft infrastructure can be developed using many emerging techniques

such as constructal theory, fractal geometry, evolutionary algorithms, data mining and machine learning.

Distributed energy

Cities and megacities consume vast quantities of energy due to their high urban density, but this concentration of buildings and people presents opportunities for distributed energy systems due to economies of scale.

District heating and cooling networks (DHC)

Cities are increasingly turning to DHC to provide heating and cooling that is potentially more energy efficient, can reduce carbon dioxide emissions and enables more flexibility at a building level. DHC have traditionally been driven by combined heat and power (CHP) systems that are fuelled by fossil fuels, but renewable heat can be integrated as well as providing a variety of fairly simple energy storage methods (including hot water, steam, molten salt, phase change materials (PCMs)). Cooling to data centres and server farms, cloud computing factories is increasingly being sited in northern regions to take advantage of natural cooling from lakes and rivers.

DHC generate data which can be used to optimise delivery of heat as well as minimising energy consumption and maximising the use of renewable heat.

Renewable energy

It is important that renewable and low carbon energy systems are integrated into a city's buildings and infrastructure. Just placing solar panels or wind turbines on roofs may not help in providing energy to cities, so it is important that the siting and orientation of such systems are optimised. It may be impracticable to install a system on one particular building, because of layout, orientation or location, but be practicable on another building. A distributed network at an infrastructure level would maximise the production of renewable energy, whilst making the overall system more cost effective.

Water-energy

We are surrounded by water, but very little of it is available for human use. We need to be much more thoughtful about our use of water. Most of the water is for non-human consumption, but we extract it from aquafers or reservoirs (which mainly come from run-off), treat it to a standard suitable for human consumption and pump it to cities. Non-potable water can be recycled for use close to the customer. Economies of scale mean that cites should re-use most of the water consumed, reducing the need for fresh water and the energy required to process and deliver it.

Sustainable cities

Sustainable development is most commonly defined as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Buildings and urban infrastructure are a major cause of unsustainable development, but one of the easiest to fix, whether it is modifying existing buildings and infrastructure or developing buildings and infrastructure that are closer to the definition of sustainable development. It is not "rocket science". It is not necessary to invent new materials, design new machines or develop new fuels to design sustainable spaces, although innovations can feed into the solutions and make a difference. It is a mainly a matter of creative design. Therefore, architects, engineers and urban designers play the most crucial role in developing intelligent buildings and infrastructure, an example of intelligent social infrastructure. If these important professions work together from concept to handover, then they will be more successful in achieving their goals, and be more sustainable, should this be one of their goals. If these professions work separately or development is linear (concept/structure/services/control/facilities management) then success is less likely.

Smart cities

The emergence of smart technologies such as robotics, AI, data mining and manipulation, and

pervasive computing has great potential to improve the lives and prosperity of citizens but has many downsides, as described in the state-of-the- art review. A development strategy for intelligent buildings should embrace the emerging technologies, but mitigate the negative effects. Cities are great engines of economic development, but as employment patterns and occupation categories change, it is the responsibility of its governors to act in the interests of its citizens to ensure that they benefit from the opportunities. Each city or urban space will have different ways of balancing the benefits and costs of the development of smart technologies, but if only a small proportion of its citizens benefit from the changes then social unrest will result. Cities are places of growth, but also places of protest and revolution.

Megacities

There are over a twenty megacities with populations exceeding 10 million people, and most of them are in developing regions of the world. This report focusses on how intelligent buildings and its infrastructure can produce a better world for the people living and working in it, whether it is employment, health and well-being, sustainable development, or technologies that connect people and improve services. However out focus tends to fall on modern cities in the developed world that have a civic infrastructure that tends to reduce the inequalities that arise when there are few checks and balances. In developing regions, where civic society is less well established, informal settlements are common and tolerated. It is important that advances in buildings and infrastructure are applicable to developing countries and the outcomes can reduce the prevalence of slums, tackle poverty and improve the life chances of people living on the margins of society.

6.5 Research Contribution

The research community can contribute to the advancement of intelligent buildings and infrastructure by gaining a better understanding of the interface between social, smart and environmental infrastructure.

Research at the interface between social, smart and environmental infrastructure should aim to;

- Gain a better understanding of the relationship between changing work patterns and health, well-being and productivity with respect to buildings and infrastructure.
- Develop techniques investigating the relationship between hard and soft infrastructure on health, well-being and productivity.
- Understand the life-cycle costs of intelligent buildings and infrastructure, using a range of scenarios.
- Develop strategies for optimizing hard and soft infrastructure.
- Develop models and methods for integrating distributed energy infrastructure.
- Develop techniques for optimizing distributed energy infrastructure using techniques including data analytics, constructal theory, fractal and evolutionary algorithms.
- Develop systems and infrastructure that integrates water and energy systems.
- Develop working methods that encourage teamwork across disciplines.
- Develop systems that integrate smart technologies (big data, AI, IoT, robotics) between buildings and infrastructure.
- Provide solutions that are practical and affordable, so that they can be applied to developing regions.

6.6 Research Agenda

Researchers need to work across disciplines to develop new thinking, so that everyone benefits from advances in intelligent buildings and infrastructure. We will need contributions from the scientific community and from the humanities. If we are to create buildings that serve the people

working and living in them then physiological, physiological and social aspects will need to be addressed as well as the scientific and technical.

The future direction of research in intelligent buildings and infrastructure should focus on:
Developing working methods that encourage team working between different disciplines from the concept stage. It should be recognised that non-technical disciplines are important to the development of intelligent buildings and infrastructure.
Ensuring that building owners and occupants benefit from development.
Ensuring that the wider community benefits from development.
Ensuring that advances in intelligent building and infrastructure is accessible and cost effective to developing regions.
Where possible, water and energy services development should be integrated.
Sustainability must be a high priority, but this must be balanced with the need of building occupants (health and well-being) and building owners (payback times, life cycle costs).
Smart technologies should be embraced, so that the benefits that they bring can be realised, but this must not be at the expense of personal liberty or privacy. Transparency is vitally important, so that data that is being accessed and manipulated is with the consent or knowledge of the individual or organisation.

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7. Sustainable urban transportation in intelligent cities

Xingxing Zhang

7.1 Air quality in underground built environment

Background and Description

Millions of people in metropolis benefit from the convenience of underground systems, which reduce the traffic congestion above the ground. However, during the recent large-scale proceeding of urbanization of developing countries, like China, the underground traffic has raised significant issues ever to the large-and-medium sized cities. One of the severe problems is indoor air quality (IAQ) in underground systems due to heavy use and overcrowding, unsustainable operation in public transportation and etc.

Most underground systems are designed as confined space where air pollutants are generated and diffused as well as enter from outside atmosphere. Hence, various types of air pollutants which bring threats to human's health are accumulated in underground systems. IAQ must be a matter of great concern because regular passages passengers and underground working staff spend considerable time in the underground system daily. Therefore, in order to ensure the passages passengers and underground working staff health, relative researches and implements are necessary for controlling the hazardous air pollutants in the underground system.

Recently, a few studies have been reported to monitor the IAQ and propose strategies to mitigate this issue. Inhalable particulate matter (PM) concentrations are typically much higher than those above ground according to some published studies, nonetheless, the substantial factors impacting the production and shape of PM are heterogeneous that rarely illustrated solitarily yet. The geographical areas, indicated in **Fig. 7.1**, discussed include Montreal (Boudia et al., 2006), New York (Ruzmyn et al., 2015), Los Angeles (Kam et al., 2011), Paris (Bachoual et al., 2007; Tokarek and Bernis et al., 2010), Mexico city (Hernandez-Castillo et al.,2014; Mugica et al., 2012; Gomez-Perales et al., 2004), Shanghai (Li et al., 2012; Huan et al., 2014), Beijing (Jing et al., 2012), Guangzhou (Chan et al., 2002), Xi'an (Gao et al., 2015), Suzhou (Cao et al., 2017), Tianjin (Wang et al., 2016), Taipei (Kam et al., 2011), Seoul (Son et al., 2012; Kim et al., 2008), Fukuoka (Chang-Jin et al., 2012), Tehran (Hosein et al., 2014), Puna (Delbari et al., 2016), Istanbul (Sahin et al., 2012), Bracelona (Moreno et al., 2014), Stockholm (Klara et al., 2012), Helsinki (Aarnio et al., 2005), Milan (Colombi et al., 2013), Rome (Perrino et al., 2015) London (Pakbin et al., 2010; Adams et al., 2001) and Birmingham (Harrison et al., 1997). The majority of this research was conducted via on-site testing of PM at different sites in the subway stations, i.e. the station hall, carriages etc., with corresponding analysis on the distribution and physicochemical properties of PM2.5 in each location in the subway station. For instance, Kam et (2012) measured the concentration of the particles in six different cities for eight years in eastern of America. Then they analyzed the correlation between death rates and the particles and they found that correlation between mortality and the PM2.5 was strong. Delbari et al (2017) reported that the mortality would increase 1.5% when the average concentration of the PM2.5 increases 10 $\mu g/m^3$, Pope C et al (2002) also got similar results. Moreover, some researchers have reported that the concentration of particles in the subway were much more than the outside environment and they were much more gene toxic which could cause more healthy problems to public (Kijnzli, Kaiser et al. 2000, Guo, Hu et al. 2014). Now there are many studies, which measured the particles in public transportation including the Metro, buses and so on (Adams, Nieuwenhuijsen et al. 2001, Cheng, Lin et al. 2008, Cheng and Yan 2011, Kam, Cheung et al. 2011, Cheng, Liu et al. 2012). In these studies, the factors

influencing concentration and distribution of PM in subway stations include seasons, weather, time, traffic density, brake system, ventilation system, passenger density, depth, design, aboveground or underground, operating duration, location, piston effect, outdoor traffic (Park et al., 2008, Li et al., 2012, Cheng et al., 2008, Hernandez-Castillo CR et al., 2014, Moreno et al., 2014, Midander et al., 2012, Aarnio et al., 2005, Boudia et al., 2006). And the measured targets or components in subway stations were outdoor climate conditions, platforms, passenger carriages, driver compartments, station offices, rest areas, ticket offices, station precincts (Li et al., 2012, Hosein et al., 2014, Park et al., 2008, Huan et al., 2014, Ruzmyn et al.,2015, Kim et al., 2008, Cheng et al. 2008, Moreno et al., 2014, Midander et al., 2012, Kim et al., 2014, Aarni et al., 2005).

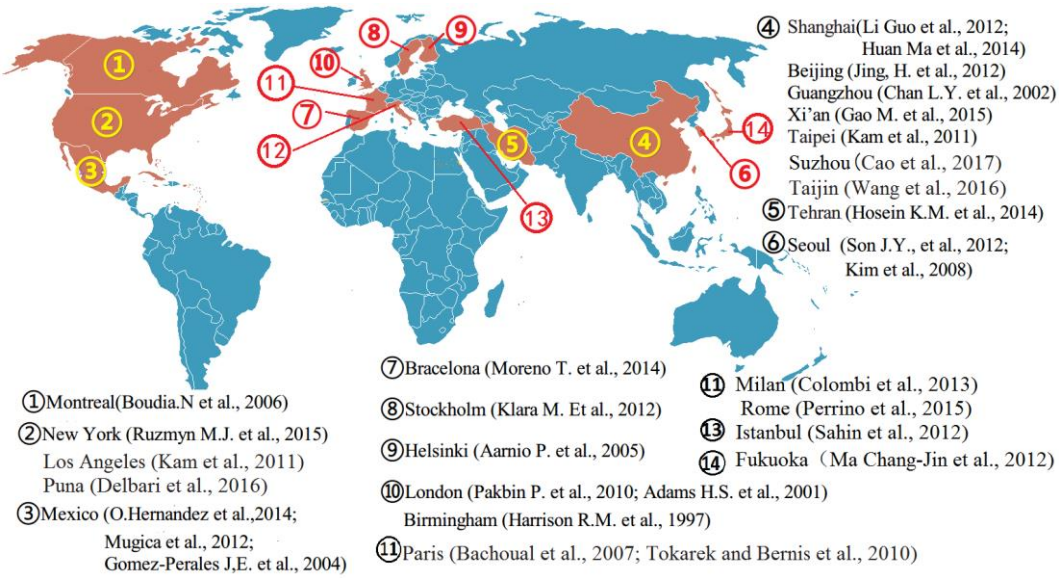

Figure 7.1 Geographical locations of research into PM2.5 in subways

According above studies, it is likely that the PM analytical results would be different if the studies were performed in another country or even in the same city, as the influencing factors and the measured targets/components may vary. To make an accurate assessment, it is necessary to carry out the local measurement and analysis. Besides the PM, coeval concentrations of CO_X, SO_X and NO_X are also significant sectors that should be investigated on underground train station platforms.

Sampling and observation are the primary method currently used for the physical and chemical characterization of IAQ in subways. The main physicochemical properties are: (1) the shape of pollutants in subways is complex and changeable; there are no stable or identical shapes identified; (2) current research focuses mainly on the elementary composition of pollutants; these chemical are not found as individual elements but as part of a compound. Current research demonstrates that the factors influencing the concentration and distribution of pollutants in subways included external, internal, human and operational factors. Pollutants sources in subways are usually divided into two categories: from the external outdoor environment and from the subway interior i.e. the perennial equipment, the ventilation systems and the train brake systems. The control strategy of pollutants relies on the features of the subway. In contrast to buildings over-ground, subway stations could be considered to be "semi open construction" and therefore obviously affected by the outdoor environment. IAQ in subway stations is dependent on the ventilation system with the control strategy provided by most of researchers being through prevention and control through ventilation. Although subway cabin air purifier (SCAP) has been used in subway carriages to

reduce pollutants concentration, there is still a lack of definite methods for the control of platform and station hall ventilation systems.

Objectives

This road map aims to bring forward the urgency and necessary of mitigating the IAQ problem in underground built environment. It seeks to advance the understanding of indoor air pollutants and pertinent measures which save energy consumption, enhanced the IAQ level, and minimize the health risk in underground, by consolidating a large set of new peer-reviewed work that highlights the implement in the IAQ improvement and sustainable operation in underground system for future intelligent cities.

Future research potential topics may include, but are not limited to:

- IAQ in underground and suspended particulate matter
- IAQ in underground and source of air pollutants
- IAQ in underground and mortality risk reduction
- IAQ in underground and season dependent model
- IAQ in underground and thermal comfort
- IAQ in underground and energy saving
- IAQ in underground and ventilation system
- IAQ in underground and online monitoring
- IAQ in underground and numerical simulation
- IAQ in underground and sustainable operation

Focus of research and development

Systematic research method: sampling and observation is the primary method currently for the physical and chemical characterization of air quality in underground built environments. Due to the complexity of undergrounds, many people are sceptical about the accuracy of results and validity of data. Further research into the theory and methodology must be completed to improve data analysis.

Characterized measurement locations and long-term data collection: most of the existing studies focus only on a certain area or a certain underground so that the research results may have significant differences due to many varying factors. The characterized measurement locations in undergrounds need to be defined and made uniform, such as carriages, work areas, public areas (platform, station hall) and outdoor environment. Since the main analysis method used is sampling and observation, large accumulations of data will be required, which must be achieved through long-term measurements in underground built environments.

R&D in different locations and scenarios: The factors influencing the IAQ in undergrounds are different from locations and scenarios. It is very likely that the IAQ would be different if the studies are performed in another country or even in the same city. To make an accurate assessment, it is necessary to carry out the local measurement and build local database for analysis.

Control against energy saving: some researchers have argued from an energy-saving perspective that air only needs to be controlled within the carriage since passengers spend most time there. It has been suggested that underground air-conditioning and ventilation should be in

mind from the very beginning of design up to final operation so as to control air distribution in undergrounds whilst consuming as little energy as possible.

Millions of people in metropolis benefit from the convenience of underground systems, which reduce the traffic congestion above the ground. However, during the recent large-scale proceeding of urbanization of developing countries, like China, the underground traffic has raised significant issues ever to the large-and-medium sized cities. One of the severe problems is indoor air quality (IAQ) in underground systems due to heavy use and overcrowding, unsustainable operation in public transportation and etc. Most underground systems are designed as confined space where air pollutants are generated and diffused as well as enter from outside atmosphere. Hence, various types of air pollutants which bring threats to human's health are accumulated in underground systems. IAQ must be a matter of great concern because regular passages passengers and underground working staff spend considerable time in the underground system daily. Therefore, in order to ensure the passages passengers and underground working staff health, relative researches and implements are necessary for controlling the hazardous air pollutants in the underground system. This road map aims to bring forward the urgency and the needs of mitigating the IAQ problem in underground built environment, especially at subway stations. It seeks to advance the understanding of indoor air pollutants and pertinent measures which save energy consumption, enhanced the IAQ level, and minimize the health risk in underground, by consolidating a large set of new peer-reviewed work that highlights the implement in the IAQ improvement and sustainable operation in underground system for future intelligent cities.

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8. Keeping Abreast with Technology

Eva D'Souza

In order to get the most out of the technology you have and to compete in the business world one has to keep abreast of emerging new technology. You deal with the technology for your personal use, at home, at work and wherever you go to connect with people and places and to deliver the work tasks. Technology is changing rapidly and to keep pace with it is not an easy task.

Having a technology awareness strategy should ease the pressure in keeping up to date with the technology. Some of the following factors should help in developing the strategy:

- List your requirements: Defining and developing specification what you want to deliver is very important.
- Define the period: Once you specify the project, defining the life span of various elements is essential
- Available resources: Engaging right resources and making sure the technology fit for purpose is the foremost
- Resilience: Any technology you use make sure it is robust and will sustain for the whole life cycle of the project
- Infrastructure: Choosing the right infrastructure to adopt technical changes, operating and maintaining and recycling techniques to meet the financial targets.

Looking forward:

We are losing the track of technology and depend more on intelligent systems and loosing human interaction. The same intelligent pace is not available when something goes wrong.

- Intelligent approach to meet the system requirements throughout the project cycle
- More reliable products
- More technical resources
- More intelligent practice in trouble shooting
- More cost effective systems

9. Digital Futures

Peter McDermott

9.1 Conceptual Framework

The impact of digital technology and artificial intelligence on business, automation and communications is transforming the world in many ways. The digital transformation is as significant as the impact of new technology in the agricultural and industrial revolutions.

In the built environment digital technology continues to have a transformative impact. The requirements and forms of many types of building, including shops, factories, offices and homes, are all changing rapidly with the digital revolution. No one is sure where what the destination will look like. Digital village halls? Smart offices? Pop up shopfront showrooms for digital retailers? Social hubs? Living pods? Virtual homes? All established building paradigms are being explored amid a new digital and globalised world. The impacts of climate change and popular unrest caused by inequality and rapid change in economic distribution reflect a more uncertain future.

The increasing prevalence of digital technology in every facet of modern life has included a significant impact on buildings. In fact, some would argue that the term "intelligent building" itself reflects an attempt to define how this innovatory and ubiquitous technology has transformed buildings and construction in the last thirty years.

From early attempts to automate control of buildings using large mainframe digital computers, to the current prevalence of distributed digital controls (DDC) in commercial and now increasingly in domestic buildings, to the redesign of the buildings themselves to reflect the organisational and increased cooling needs of information and communications technology (ICT), these changes have been immense.
Moore's law states that computer power doubles in power every 2 years and even thought this pace of change is set to slow, the new leaps forward in the field of Artificial Intelligence (AI) will soon impact design, construction and operation of digital buildings.

9.2 State of the Art

Most buildings currently use DDC to control their mechanical, electrical and public health (MEP) services. In a typical modern building, small digital computers typically called controllers (DDC), are distributed throughout the building. They monitor and control the local equipment in order to achieve the internal conditions and energy performance required by the occupants and legislation. The digital software applications used in these controllers are normally based on traditional sequential Boolean logic and three term control loops. Fuzzy logic and machine learning programmes are very rare.
In larger buildings, these discrete controllers are networked together with a personal computer or server /client computer system. This provides a human supervisory arrangement usually implemented by a real time graphical user interface. This networked system is called a Building Automation and Control System (BACS) or Building Management System (BMS), sometimes a Building Energy Management System (BEMS). Where the control of the MEP is integrated with other digital systems in the building such as CCTV, access control, fire alarm systems etc., the system is often called an integrated Building Management System (iBMS).

9.3 Future Scenarios

Several potential development trajectories for digital control of buildings are apparent. Commercial market pressure, user preference and security concerns will determine which

approach prevails or dominates in the various applications.

Increasing use of cloud computing, where the digital software is hosted in remote data centres, offers the possibility of building automation as a remote service. Buildings would consist of MEP equipment with appropriate imbedded networked sensors and actuators. The digital intelligence will be provided and hosted offsite and delivered via the internet by specialist providers. These providers could also add value by use of "big data" analytics using machine learning and artificial intelligence (AI) to optimise the performance of building services. This scenario would offer the suppliers the benefits of a service type business model and the ongoing revenues associated with it. For the building owners and users there is the promise of setting business orientated KPIs for the specialist providers while giving them the freedom to focus on their core business. Whether this constitutes a virtual Intelligent building or rather a dumber building that is merely a component of a larger "Intelligent Organisation" is a debatable point. Opening up the building control devices and networks to the internet offers a huge target and opportunity for malicious fun for hackers, criminal gangs and state cyber warfare agencies. Cyber security becomes paramount in preventing a possible panacea for building performance become a Trojan horse for malevolent action by third parties currently unable to gain access to the buildings and people and organisation that inhabit them due to traditional and well understood physical security measures.

Another development trajectory for digital control could be the increasing use of packaged MEP equipment supplied with their own on-board DDC. The software could be optimised by the manufacturers to the specific applications for the functionality of that packaged equipment. The data from the packaged digital controls is then merely agglomerated via a standards based open protocol network to an integrated user interface. This would create a secure integrated building management system (iBMS) for the building. In this scenario, the building still retains the digital intelligence and therefore it is, in itself, an Intelligent Building and can operate as such without the connection to the wider internet and cloud based services Individual equipment suppliers will monitor and their own specific applications and data can be gathered locally and exported for external data analysis as required without the security risks of permanent online transparency.

These technology scenarios are a subset of much bigger those societal changes driven by increasing globalisation, urbanisation, growing wealth in-equality, aging populations, and climate change. The biggest impacts of digital transformation will be the increasing automation of human work, the subsequent redundancy facing many tax paying workers but also possibly prefacing super-abundant production and expansion of leisure time. This will force a paradigm shift in how society organises itself and distributes the fruits of digital production throughout the human population. The big question will be that faced only by the very wealthy in the past: What will we do with our time? And in our field the smaller one "How will this affect our buildings?"

9.4 Development Strategy

Large internet giants like Google and Amazon are following the offsite intelligence scenario as this plays to their strengths in data centre provision and big data analytics.
The traditional suppliers of BMS and process automation are developing ever more sophisticated and cost effective products to support DDC or "edge computing" where the digital intelligence is distributed locally near point of use and retained within the building

9.5 Research Contribution

Academic Research could contribute by developing the basic knowledge of digital controls theory and application within buildings. Optimisation involves meeting sometimes competing criteria of occupant comfort, energy use, carbon emissions, and capital cost. Metrics that quantify

these parameters and assist the trade-offs optimisation requires can help with decision making.

9.6 Research Agenda

Future academic research could contribute by examining the relative costs of the differing approached to providing digital automation and control in different applications, markets and scale of buildings. Research in the better application of data analytics, machine learning and AI as applied to building performance and optimisation could also be beneficial.

For the bigger digital society picture more research in the market and ownership models of technology companies and the impact of un-equal income distribution and increase leisure time on human health and wellbeing would help provide evidence for the ongoing political deliberations on future economic and social policy.

The impact of digital technology and artificial intelligence on business, automation and communications is transforming the world in many ways. This digital transformation is as significant and disruptive as the impact of new technology was in the previous agricultural and industrial revolutions.

In the built environment digital technology continues to have a transformative impact. In fact, some would argue that the term “intelligent building” itself reflects an attempt to define how this innovatory and ubiquitous technology has transformed buildings and construction in the last thirty years.

From early attempts to automate control of buildings using central mainframe digital computers, to the current prevalence of distributed digital controls (DDC) in commercial and increasingly in domestic buildings, from mandatory BIM to the redesign of the buildings themselves to reflect the needs of ubiquitous information and communications technology (ICT), these changes have been transformative.

Differing trends in digital control of buildings are apparent. Commercial market pressure, user preference and security concerns will determine which of these approaches prevails or dominates in the various applications.

Increasing use of cloud computing, where the digital software is hosted in remote data centres, offers the possibility of building automation as a remote service.

The traditional suppliers of BMS and process automation are developing ever more sophisticated and cost-effective products to support DDC or “edge computing” where the digital intelligence is implemented locally.

Which strategy eventually succeeds will be determined by the developers and users of the built environment.

10. Upskilling for technology enhanced collaborative working

Tong Yang, Rosangela Tenorio

Building information modelling (BIM) gets people and information working together effectively and efficiently through a set of interacting policies, processes and technologies (RICS 2014). BIM implementation has been changing the dynamics & behaviour of the design-construction supply chain, unlocking new, more efficient & collaborative ways of working. Meanwhile, this digital platform enables forensic tracking of high-quality information to support business outcomes through true collaborative effort amongst all stakeholders in the AEC industry (Holzer 2016; Strong & Burrows 2017).

10.1 nD capacity of BIM

Multi-dimensional implementations of BIM enable the integration of knowledge management systems and empower handling and sharing of digital information during the building's lifecycle (B1M 2015). Inclusion of accumulated information to building's operation phase through nBIM enables better decision making on design choices for optimal economic, environmental and social sustainability.

Figure 10.1 Illustration of 6D BIM (B1M 2015)

• 3D: The shared information model in a Common Data Environment (CDE). 3D information model includes graphical digital prototype of a physical building embedded with non-graphical information of actual building elements and systems for design analysis, visualization, optimization, and lastly, project data handover to a client at completion.

• 4D: (3D + time) Construction planning and scheduling visualisations. Project scheduling allows project team to map timings onto activities, simulate planned work is safely, logically and efficiently sequenced, ensure proper logistics, space utilisation in the construction phases of the project.

• 5D: (4D + cost) Cost estimation. The model uses intelligent content objects, various participants (architects, designers, contractors and owners) can use the model for real-time cost planning and trade verification. Real BIM objects from manufacturers will make cost calculation more accurate.

• 6D: (5D + operation and maintenance) Project lifecycle information. Owners/Facility managers

can use the model or export BIM objects property information to existing FM software to operate and maintain the building with an integrated view of a built-asset throughout its life cycle, including constructability, sustainability and future-proofing factors.

10.2 Creative play and collaborative learning

Digital technologies enabled BIM collaborative processes to significantly improve the efficiency of design, construction and operation, and provide a platform for continuous upskilling for all (Klaschka 2014; Sanchez et al. 2016). Since the invention of LEGO bricks 60 years ago, it is still a legendary toy embracing the principles of systematic creativity into educational play. One of the new comers, 'littleBits', a set of interchangeable electronics modular snapping blocks introduced programming through simple and fun opportunities for creative design in various cartoon/drama themes (Bdeir 2012). Meanwhile, playful and community engagement learning activities were designed to create a successful collaborative environment- The Plug in units, that encourage teamworking and social learning to think, create, operate and maintain buildings and reuse it sustainably, productively and responsibly (Tenorio et al. 2018).

New generations of AEC students are very familiar with virtual gaming settings and generally motivated in the teamwork approach assisted by BIM-enabled visualization and information sharing (Sinclair 2006). Collaborative working is required to break the tradition of working in silos and sub-optimal work sequences, so the learning and training programmes would be benefited through multi-disciplinary cross-faculty curriculum planning and management (Jin et al. 2017) as current changes happening in the industry is depicted in Fig. 10.2 (Bernstein 2015).

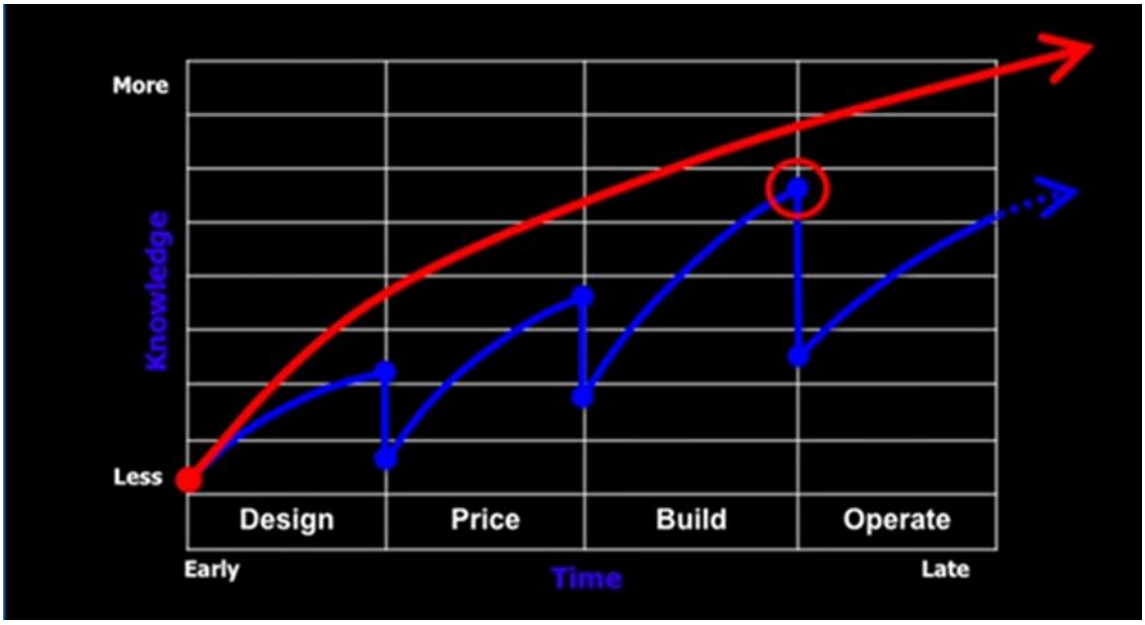

Figure 10.2. Collaborative information and knowledge management through a building's lifecycle (Bernstein 2015)

10.3 Upskilling and managing changes

As the PESTLE factors (Political, Economic, Socio-cultural, Technological, Legal and Environmental) that influence all decision-making will be constantly shifting, BIM technology and processes provide a dynamic integrated learning platform/facility of sharing best practices and new skillsets (Fig10.3) for AEC workforce (Succar 2009).

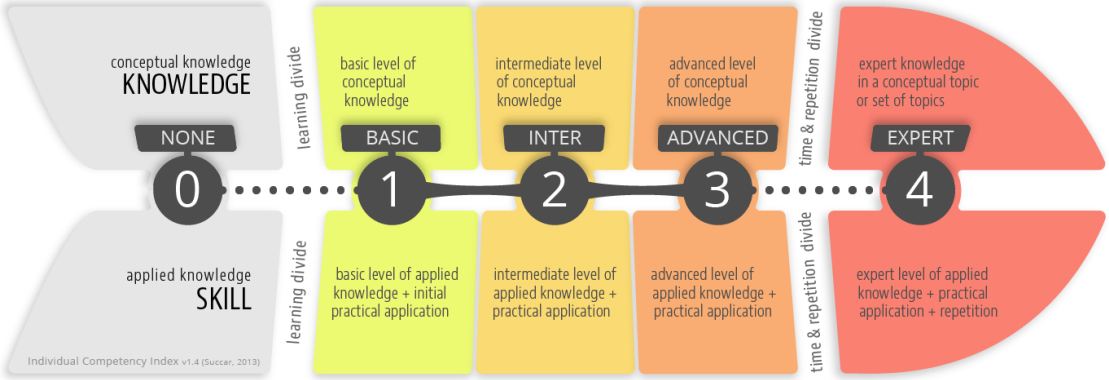

Figure 10.3. Individual BIM Competency Index (http://www.bimframework.info/competency/)

International standard ISO19650 supports the alignment of BIM standards to get a global industry working in a consistent and intelligent way. BIM skills learning and development must adapt to variations of PESTLE in a rapidly evolving industry. Effective change management with inclusive and open workflow of BIM will anticipate the impacts of emerging disruptive technologies, ever-more profound integration between information sources through all phases of projects, and continuously industry wide digital transformation with future-proof skilled workforce.

While universities are facing constant competition to attract students and keeping up pace with technology changes, the timely tasks for maintenance and renovation of ageing infrastructure with funding constraints could be the most suitable onsite learning opportunities and challenges for students. AEC students as the ambassadors of student communities could participate in key stakeholder groups (project sponsor, end user and project instigator) engagement meetings, are actively included in the communication process of planning and making technical, design and management decisions.

In addition to sound digital technology skills, students also need to acquire essential soft skills of effective cross-disciplinary collaborative working (Llewellyn 2015). Through project-based experiential learning on BIM implementation from the perspective of the lifecycle of a built asset, students can communicate with peers, academics, the supply chain, clients, customers and local government, and delve into best practices in the real-world. Decades of practical lessons learnt could be categorized and condensed into benchmark case studies through closer academic-industry collaboration. By producing virtual projects with real client brief for group learning, students would be encouraged to create ideas, make mistakes through learning-by-doing, and deliver in line with clear industry requirements and expectations to bridge the performance gap (iStructE 2017).

Students and staff with their mobiles and IoT devices could be a part of high resolution active human sensor network for intelligent and sustainable university estate operation. Big data analytics communicated through AI assistant could attract students to experience the first hand human-building interaction and occupant behaviour impact on live building performance dashboard (fig. 10.4). Through informed decision making on which data needs to be tracked over time for obtaining insight on building performance, students are trained to filter out noise and junks in the big data cloud and develop their critical thinking skills.

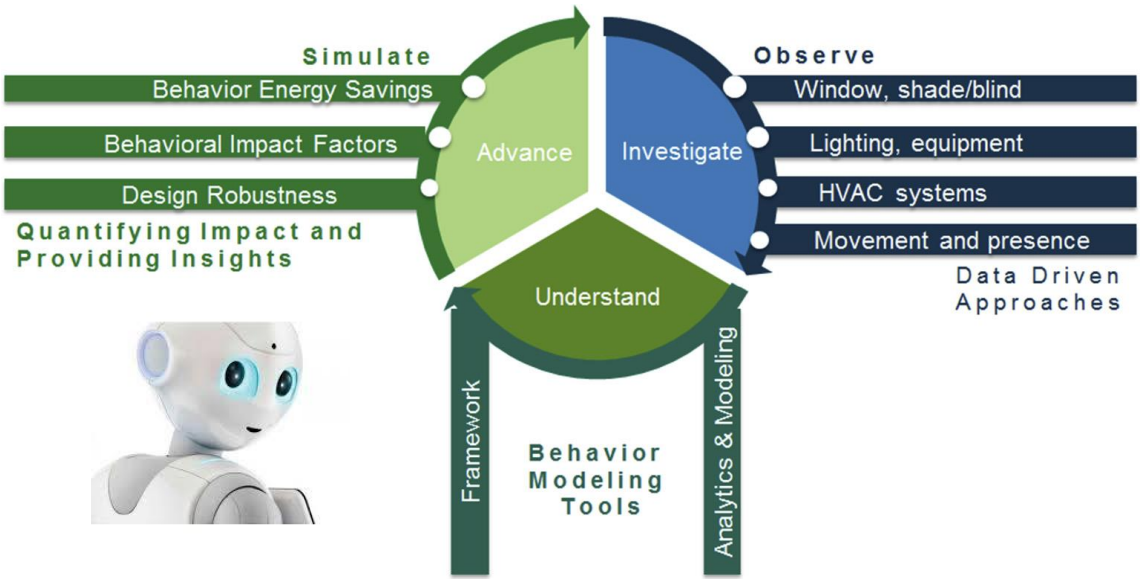

Figure 10.4. The human–building interactive energy behaviour loop (Hong et al., 2016)

10.4 Open source intelligent buildings and social infrastructure for the future

In our digital age, the open building concept (Kendall 2006) evolved and transformed with latest smart technology advances, AI enhanced design automation, offsite construction, etc. Futuristic sustainable intelligent buildings and cities could be realized by nurturing crowd based open source design and collective social infrastructure creation to improve the quality of life and the well-being of citizens (Sinclair 2006, Ingels 2016).

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11. Wellbeing homes

Pete Halsall

Wellbeing homes are not an entirely new a concept; although for the last 50 years or so this idea has been more about the avoidance of ill health, rather than the augmentation of health. Clearly the focus of wellbeing homes now needs to return to how quality and longevity of life can be enhanced and extended, sustainably, so that people can live longer, happier and more fulfilled lives, with the wellbeing home as a key instrument for this. Frank Lloyd Wright made big promises, or at least big assumptions, for how his homes could impact on the quality of lives of their residents: " *People who live in these advanced houses must have a greater feeling for life, and be more themselves. It can be very liberating to see so many elements of nature.*" Those designing and developing the wellbeing home must take on this level of confidence and ambition, applying it to a contemporary setting. We are now in a period of quite extraordinary and unprecedented change and disruption - with the likelihood in the very near future of autonomous cars, digital lives, genetically modified babies, extraordinary technology - but what will all of this mean to how, and where we live, and to the quality of our lives ? At the same time as we race towards potentially exponential technological development, we are becoming increasing at odds with both the natural environment, but also potentially with our own nature. Surely a wellbeing home is one that, fundamentally, seeks to reconcile these increasingly dramatic and opposing forces so that we really need to live in much more natural and naturalistic environments, being in touch with and at ease with nature and our own nature, whilst enjoying the fruits of technology and harnessing hyper change to enhance wellbeing.

Ironically, the first thing that we have to do then is to get people as much out of their homes, as into them. Estimates vary, but it seems that in the West we now spend up to 90% of our time indoors; with the unsurprisingly attendant health issues - both psychological and physiological ensuing; social isolation, insufficient exercise, obesity, increasing dislocation from both nature, and therefore the corollary of that, an increasing dislocation from our own nature. So, with no small amount of creative tension, the essence of a wellbeing home must be one which we are both happy to be in, and at the same time, one which we are happy to not be in. The wellbeing home must be conceived as one which is as much outdoors as indoors, a lifestyle if you wish that has both the hardware of bricks and mortar, but also the software of increasingly complex and imaginative lifestyle choices.

In conceiving of the wellbeing home in a much more flexible way, then we need to think in terms of living in the city, and only, in part, in our homes. This indeed reflects how many Asian cities now are; In Seoul in South Korea, birthday parties are held in public parks, not lounges, rooms to play video games are rented with friends and not always now played in bedrooms, studying is done in generously sized coffer bar lounges or bookshops; indeed home is the last place that you go to after work, rather than the first place. So that the effect of all of this is that a wellbeing home makes no sense if we don't at the same time have the wellbeing city. Increasingly we should think of the city as where we live and the home as just one part of an increasingly complex patchwork of places, services and new ideas yet to be invented. We must then seek and strive equally for both the wellbeing home as well as the wellbeing city; the whole to be natural, vibrant, interesting, challenging, sociable, productive, full of multi-sensory experience, beautiful - and safe, both physically and also digitally, free of crime and cybercrime. Maybe we should think more about the nuclear family model, which is now sub-optimising how we live - perhaps it

is now the ultimate barrier to a more collaborative and sharing based society where we must now with scarce optimise housing, cities and economics.

Focusing on the wellbeing home as a necessary subset of the necessarily wellbeing based city, we can see that the environmental aspects, both inside and out, are fundamental. We already know that our definition of what is functional needs serious re-thinking, and has largely been framed in the last 150 years around a startling ignorance of our own nature; so that a beautiful and engaging environment is not something which is nebulas or destroying of efficiency and utility, but rather something which enhances and optimises our psychological and physiological functioning - thus increasing utility and efficiency; the ultimate, 'value added' experience if you like, but played out in the everyday with the objective to enhance and extend both quality and longevity of life.

The state of the art for the wellbeing home has to start with high quality architecture, itself, arguably, the highest of all art because it can contain and contextualise all other art, and indeed science and technology; this must be the framework and concept around which everything else functions. Indeed, it was Frank Lloyd Wright who also said "*I believe that a house is more of a home by being a work of art.*" Some may say that this is an impossible dream - but the reality of modern manufacturing and consumerism is that pretty much everything becomes economically available to the majority, not just the minority of the population, in due course. We have then to start with economic and development models which free the market and the forces of innovation to deliver what everybody wants - a beautiful, wellbeing home, in a beautiful, wellbeing city, at prices that we can all afford. 3D printing and other advanced manufacturing techniques are making the decorative, the beautiful, the fractal - very readily available, and so there are increasingly no excuses for a lack of beauty.

From a technological stand point, we are now at a point we were are no longer constrained, certainly in the same way that we were in the past, by what technology is available - we can co-create, curate and commission new technologies to serve a plethora of lifestyle and wellbeing needs around the home. We must mine the huge amount of industrial and academic research to find new scientific understandings and to create new technological paradigms and specific solutions. The increasing blurring of what is home, what is housing technology, and what is 'us', rapidly reframes and extends what is possible. Fitbits which measure our skin temperature can be used to control heating systems - our outward breath can be monitored to set and vary ventilation controls - in each case room by room. Why not? Remember, the limit of technology, certainly in its conceptualization, has always been the limit of our imagination.

To accomplish all of this we must as part of creating the wellbeing home and the wellbeing city take back our democracy and increasingly advocate strongly and determinedly for change at the city level; for genuine and meaningful citizen participation in city governance. Citizens know better than the vast majority of designers now, and that is what is beauty is. If we believe that democracy is worth it, and that it counts, then we should not bat an eye lid. The wellbeing home and the wellbeing city need to be thought of as key aspects of a sustainable, egalitarian and truly democratic future; our first job then is to think, to design, to realise phenomena and new concepts at the socio-economic, and also at the pscyho-political levels, so that we can create the context in which the wellbeing home can become ubiquitous, by being affordable. In other words if we are to have the wellbeing home and the wellbeing city then we must first create the political and economic context in which this can happen.

12 Bioelectromagnetic Design

Isaac Jamieson

12.1 Conceptual framework:

What are we talking about? Game-changing interdisciplinary design/disruptive innovation that blends cutting edge biological research with technological innovation and international best practice to create new design paradigms for biologically friendly buildings, technologies and environments.

Technological innovation

An essential component aiding advancement in the new 'Bioelectromagnetic Age' is the creation of more bioelectromagnetically friendly intelligent and responsive buildings and technologies.

The need for detailed research into how to biologically optimise electromagnetic exposures in the built environment is long overdue, with rapid progress, development and deployment of effective (often low cost) technologies and techniques appearing possible in many areas.
This ground breaking initiative is also set to help the building industry better tap into the global Wellness Market, a trillion dollar industry that is already three times larger than the worldwide pharmaceutical industry. It represents disruptive innovation at its very best.

Enhancing health and well-being

We are presently experiencing exponential growth in environmental exposures to manmade electromagnetic phenomena. Often little thought is given to their potential positive or negative biological effects, a shortfall that can be actively addressed.

It is very important for us to investigate how healthier "next generation" bioelectromagnetic environments and technologies can be created.

12.2 State of the Art

What are the issues and where are we today?

Numerous studies demonstrate that electromagnetic phenomena can be biologically active. Knowledge already exists on how we can create healthier environments and this can be readily built upon.

Bioelectromagnetic health matters

The World Health Organization/International Agency for Research on Cancer already classifies radiofrequency (RF) electromagnetic fields "*as possibly carcinogenic to humans (Group 2B)*". Some experts suggest RF radiation should be upgraded to Group 2A, 'probably carcinogenic', or even Group 1 'carcinogenic'. [Research also indicates that 5G frequencies and other millimeter wavelengths can be biologically active even at very low intensities].

Mains frequency magnetic fields too are presently classified as group 2B carcinogens (WHO/IARC 2002), and there is evidence that excess electrostatic charge and mains frequency electric fields [at levels encounterable in many indoor environments] can, at least indirectly, negatively impact health. Studies have additionally shown that the types of lighting and glazing that are specified can have marked biological effects. Again, healthier solutions can be specified and/or created.

Such findings indicate that a strong opportunity exists for the building industry to be better educated on how to optimise exposures, create "Win/Win situations", and protect against risk.

There is a need to reduce "electromagnetic pollution"
This present initiative helps address the need to optimise biological performance through intelligent design and create safe environments for individuals who are electromagnetically hypersensitive (EHS) or otherwise adversely affected by electromagnetic pollution. It additionally helps aid productivity, fosters wellbeing, better protects the environment, and creates fertile ground for bio-friendly innovation.

[As an aside, "electromagnetic pollution" also hampers the effective use of technology. IEEE SPECTRUM reports electronic noise is drowning out the Internet of Things, and will become a very expensive problem to deal with unless action is taken now].
Estimates for the number of individuals with EHS vary, with several countries reporting it may affect between 4-10% of their populations. In the UK alone this would correspond to approximately 2.5 to 6.3 million people, a number well in excess of the 1-2% of its population using wheelchairs for which the building industry already makes provisions.

Other members of the community are also considered by some experts to be at higher risk from exposure. It is our duty to create inclusive environments that minimise / avoid such risks and act to actively improve wellbeing.

Need to design in inclusivity and wellbeing initiatives into projects
The WELL® Building Standard already takes into account the need for EMF-protected design. It is becoming increasingly important that we seek to intelligently optimise the electromagnetic characteristics of our designs to address such matters.

Best practice can help ensure that the environments and technologies we design and/or specify in this "Bioelectromagnetic Age" aid social cohesion and comply with the United Nations Sustainable Development Goals (SDGs).

Liability issues
Many insurance companies are now refusing to cover claims linked with electromagnetic radiation. It is vital that we are in the forefront in addressing such challenges, and use this occurrence as a springboard for beneficial change and innovation in our industry.

Legal action and ruling issues
There have already been legal actions and rulings won relating to the effects of electromagnetic pollution. Cases appear likely to greatly increase unless proper proactive measures are put in place.

Stakeholders
Stakeholders in this issue include: building professionals; medical doctors; members of the general public (including those who are EHS); scientists; manufacturers; ministries of health; NGOs; product designers; and technology companies.

'Win/Win' situations are possible, and can raise the accomplishments of Intelligent and Responsive Buildings to a whole new level.

We have a duty to our future selves to develop robust policies and practices that will help

continually improve the health and wellbeing of individuals and the environment.

12.3. Future scenario

In 10 years' time we wish to be in a position where "bioelectromagnetic environmental issues" are openly addressed in the design of buildings, technologies and environments, with ongoing best practice involving multiple stakeholders continually seeking to refine and improve measures taken.

By that time it is intended that many buildings will have biologically optimised "low anthropogenic EMF zones" (so called "white zones") as standard, as will the infrastructures that allow people access to them. Some may also feature special "bioelectromagnetic climates" that further aid individual wellbeing and performance.

3D EMF design templates

It is envisioned that 3D EMF templates will be used as standard as spatial planning tools to help reduce individuals' exposures to "electromagnetic pollution".

Optimised exposures to electromagnetic phenomena

Exposures to electromagnetic phenomena will be fine-tuned (wherever possible) to aid circadian rhythms, general biological functioning, and task performance.

The effects of electromagnetic phenomena will be taken into consideration as standard, as will the need to have key areas and green infrastructures free from "electromagnetic pollution" to help cater for those who have become sensitive to electromagnetic phenomena, those who wish to live in more natural electromagnetic environments on a daily basis as a matter of personal choice, and those wishing to have "digital detoxes".

It is intended that "white zones" / biologically optimised exposure zones will be provided as standard in many public spaces including, health centres, hospitals, grocery stores, petrol stations, libraries, parks, theatres, etc., to permit inclusive design that caters for those who are EHS. It is also intended that 'white zones' will be created within housing developments, workspaces, etc., for similar reasons.

It is expected that in 10 years' time, provision of external low-EMF green space and low-EMF green corridors will become a design norm as we learn to work more in harmony with nature, rather than against it, and gain greater understanding of the electromagnetic nature of all life. Ideally by this time period, all technologies will be transitioning to more bio-friendly versions of their former selves.

[With proper planning such initiatives can also contribute towards electromagnetic pulse (EMP) protection. At present little is done to counter such threats in the design of the built environment, even though they are Tier 1 risks. It is suggested that ≥20% of all developments should be low EMF and EMP-shielded with on-site power generation. Such provision will significantly improve national security and resilience].

It is envisioned that bioelectromagnetic design skills and EM shielding skills will be in high demand.

12.4 Development strategy

Much of what needs to be known to create safer, more "bioelectromagnetically friendly"

buildings, environments and technologies is already known. A great deal of this intellectual challenge is already solved, or provides strong clues as to what areas of investigation need to be taken to determine the best solutions. The opportunities for game-changing innovation are virtually endless.

The willingness to open our eyes to the exciting opportunities that exist is all that is required to take the first step into a brave new future.

12.5 Research Contribution

R&D can make substantial contributions through bringing together and linking knowledge and best practice from all around the world on areas that can impact "bioelectromagnetic health". It can also be of tremendous service in testing theories and refining what is already known. It is predicted that funding such areas will provide a sound return on investment for those interested in creating a more bio-friendly world.

12.6 Research Agenda

The worldwide research agenda is to assemble interdisciplinary teams of renowned experts and suitably qualified additional stakeholders to blend cutting-edge biological research with technological innovation, international best practice and "real world" needs.

Work required includes detailed investigation of the potential beneficial and detrimental effects of exposures to a wide variety of electromagnetic phenomena, and best practice standards that exist to date. Luckily much initial work in these areas has been undertaken and it provides us with indications of what is required to progress still further with good chances of success.

It is envisaged that such a wide-scale interdisciplinary international effort will reveal numerous potential technical breakthroughs and best practice improvements that can substantially enhance the design and operation of intelligent and responsive buildings. With the air of openness and international unity being encouraged for this topic, and the great breakthroughs that are likely, it is envisaged that cooperation between research and practice will be high.

The 'Win/Win' situations that are achievable can raise the abilities and performance characteristics of Intelligent and Responsive Buildings to a whole new level. They can also change the face of technology as we know it. The Dawn of the "Bioelectromagnetic Age" is upon us.

Conclusions

Derek Clements-Croome

The Roadmap has distinctive themes which set the pathway for the future.

WHAT ARE INTELLIGENT BUILDINGS?
Intelligence has three parts cognitive, emotional and practical. A building needs to reflect this. So an intelligent building will responsive to people in terms of not only being functional but to the human senses besides serving a community in the location. It will be resource effective in terms of energy , water and waste with low pollution. It will be smart in terms of technology selected to enable the systems to respond effectively but also make them easier for people to use. Today there is a focus on health and wellbeing and so intelligent buildings must produce a healing environment. Buildings need to be functional and practical but also expressive. Equally important is the infrastructure that services buildings and the people moving between them.

LESSONS FROM HISTORY
Intelligent buildings are not new. Various periods in history just express them in different ways. Vernacular architecture shows how people from all parts of the world have adapted to working and living in all sorts of climates. From the igloo in the Arctic to yurts in Mongolia and the Malaysian house all are examples. The wind towers and mashrabiya in Islamic architecture show how natural ventilation and shading can be achieved in a natural and aesthetic way. The basic principles of passive design are embedded here in the vernacular across the ages and is highly relevant today in order to reduce energy consumption. These basic principles remain true today even for highly smart buildings endowed with high technology.

LESSONS FROM NATURE
Biomimetic architecture uses Nature as the inspiration because it is economic in use of energy and materials. Whether it is spiders webs that stimulated Frei Otto to build lightweight tension structures or the radiolarian which were in Buckminster Fuller's mind for his designs of geodesic domes besides many more examples leads us to believe Nature has an abundance of examples which can inspire architecture. Bernard Rudofsky's book in *1964 Architecture without Architects* is a reminder of this belief.
Biophilia is our innate love of Nature and it can calm and soothe working or living conditions so they are less stressful.
Bio- facades using smart bricks embedded with microbes that generate electricity; chemo luminescence---like the fireflies or angler fish-- for lighting without electricity ; algae living walls to harvest and derive bio- gas; use of walls with artificial leaves using photosynthesis to generate hydrogen are just some ideas.

BUILDINGS FOR PEOPLE
Our designs affect people's physical, mental and social wellbeing. The environment with other factors is a significant cause of absenteeism and presenteeism which in the UK cost about £100bn a year So for many reasons including productivity the intelligent building must be a healthy place to live and work. The latest work by World Green Building Council and their regions; BCO and others are reviewing the methods for rating health and wellbeing including the WELL Standard, Fitwel and Flourish models among others which give a holistic assessment of physical, perception and economic factors.

ROLE OF TECHNOLOGY
The rapid pace of technology and the opportunities it offers cannot be ignored. However there are downsides too . Buildings need to focus on simplicity not complexity. The Fourth Revolution is underway and robotics; quantum computing; internet of things; smart materials; nanotechnology; 3D/4D printing; artificial intelligence are some of the technologies which are already impacting architecture. Intelligent buildings need to be adaptable to change to use the opportunities offered by these technologies for new and old buildings.

SUSTAINABLE ARCHITECTURE
Effective and efficient use of resources like energy ,water and waste is vital so CO2 emissions and pollution are low. Low or neutral carbon buildings can be improved so we see the emergence of carbon positive buildings. Buildings can become energy generators.

DECISION MAKING
At every stage in planning, design, construction , commissioning and post occupancy evaluation decisions have to be made which offer continuity from one stage to the next. There has to be a vision. There has to be connectivity between all the stakeholders. The latest work on decision making with respect to 'wicked' problems will be reviewed and a transdisciplinary approach with collective thought advocated using holistic and systems thinking. Success depends on stakeholders collaborating as an integrated team. Long term thinking is essential with an emphasis on value not short term costs.

POST OCCUPANCY EVALUATION OF INTELLIGENT BUILDINGS
We need to share successes as well as failures so we do not keep repeating the same mistakes. Let us be an open forum to learning from each other.

Intelligent Building have existed for thousands of years but different centuries and cultures express them in different ways so what is an intelligent building? Is it one that serves the needs of people in functional ways but is also beautiful not just visually but in the simplicity and sensory ways it achieves these needs. Examples might be an igloo, a Japanese tea house, the Malaysian house or a courtyard design but there are many other vernacular types throughout history each offering ingredients that make up the recipe for the essence of an intelligent building.

In the 21st century intelligent buildings tend to be ones that are very technology driven but already we can see the impact of changes in society in that they need to be responsible for health and well-being of the occupants so bring in a caring and humane approach that offsets the hard faces of construction and technology. Too often an intelligent building is reduced down to the choice of a building management system but there is much more to it than that.

During his lifetime Wotton published two works: *The Elements of Architecture (1624),* which is a free translation of *de Architectura* by Marcus Vitruvius Pollio, executed during his time in Venice and a Latin prose address to the king on his return from Scotland (1633). Wotton shares authorship of the quote "Well building hath three conditions: firmness, commodity, and delight," with Vitruvius, from whose *de Architectura* Wotton translated the phrase; some have termed his Elements a paraphrase rather than a true translation, and the quote is often attributed to Vitruvius. Today that phrase might be durability, resilience, function and beauty.

Of course these are basic primary needs but they can be interpreted in various ways. Each building will be nuanced in a particular way according to the design team. It is a composition but unlike a music score composed by one mind buildings are a composite of many thoughts from many minds

that make up the design team, many educated in different ways too, and therein lies the source of many problems. Attaining connectivity of thoughts to achieve a vision is not easy but when successful is powerful.

Can Intelligent Buildings provide alternative approaches to heating ventilating and air-conditioning and buildings? Lessons from history as well as the natural world show that they can. These feature in Chapters 2 and 3. Throughout history clean air, sunlight, sound and water have been fundamental to the needs of people. Today, sensitive control of these needs may use either traditional or new solutions, or a blend of these, but we have to remember that the built environment is fundamental to mankind's sense of well-being and it is the totality of this idea that we need to understand and value even in this low carbon economy age. Intelligent buildings respect these values for the individual, the business organisation and for society, and we can learn a lot about intelligent buildings by looking at the history of world architecture and seeing how people have adapted buildings to deal with the rigors of climate and the changing face of civilisation. There are also lessons from Nature because animals and plants have evolved to use materials and expend energy optimally in the various changing and dynamic environments across the world in deserts, arctic regions, hot-humid, hot-dry or temperate climates. Similarly buildings are now having to absorb the impact of the technological age, but the implications of climate change and the need for healthy working conditions are now dominating our thinking as people become more knowledgeable about the impacts of the environment not only on ourselves as individuals but also in the context of communities locally and globally .

Intelligent buildings should be sustainable, healthy, technologically aware, meet the needs of occupants and business, and should be flexible and adaptable to deal with change. The life cycle process of planning, design, construction, commissioning and facilities management including post-occupancy evaluation are all vitally important when defining an intelligent building. Buildings comprise many systems devised by many people, yet the relationship between buildings and people can only work satisfactorily if there is an integrated design, construction and operational team possessing a holistic vision working together from the commencement of a project. To effect a common vision, it is essential for architects, engineers and clients to work closely together throughout the planning, design, construction and operational stages of the buildings total life cycle. This means that planners, consultants, contractors, manufacturers and clients must share a common vision and set of intrinsic values, and must also develop a single understanding of how the culture of an organisation with its patterns of work are best suited to a particular building form and layout when served by the most appropriate environmental systems. A host of technologies are emerging that help these processes, but in the end it is how we think about achieving responsive buildings that matters. Intelligent buildings can cope with social and technological change and should be adaptable to short-term and long-term human needs, however, from the outset this must be delivered through a vision and understanding of the basic function of the building.

We need to consider how buildings affect people in various ways. They need to be expressive as well as being functional. The environments they create can help us work more effectively because they can present a wide range of stimuli for our senses to react to besides satisfying our primeval needs of warmth, safety and security. Intelligent buildings are designed to be aesthetic in sensory terms including being visually appealing; they are buildings in which occupants experience delight, freshness, a feeling of space, they should invite daylight into their interiors, and should provide a social ambience which contributes to a general sense of pleasure and improvement in mood. In Chapter 4 I introduce the idea of flourishing environments. Of course the culture, the management and job satisfaction are key but this does not subdue the importance of the built environment.

Buildings consume a great amount of energy and water in their construction and during their total life-cycle. They use large quantities of materials and aggregates and generate waste and pollution at every stage of their production. It is no longer acceptable to consider a building and its systems in isolation from its social impacts. This becomes critical with the growth of megacities which is part of a rising trend towards urban living. Modern liveable cities comprise intelligent and sustainable buildings and infrastructure however they should be designed to show respect for the natural environment and the health of the inhabitants. Sustainable and intelligent cities are composed of buildings supported by intelligent infrastructures created for the well-being of residential, commercial and industrial communities.

The key criteria for achieving good quality intelligent buildings are:

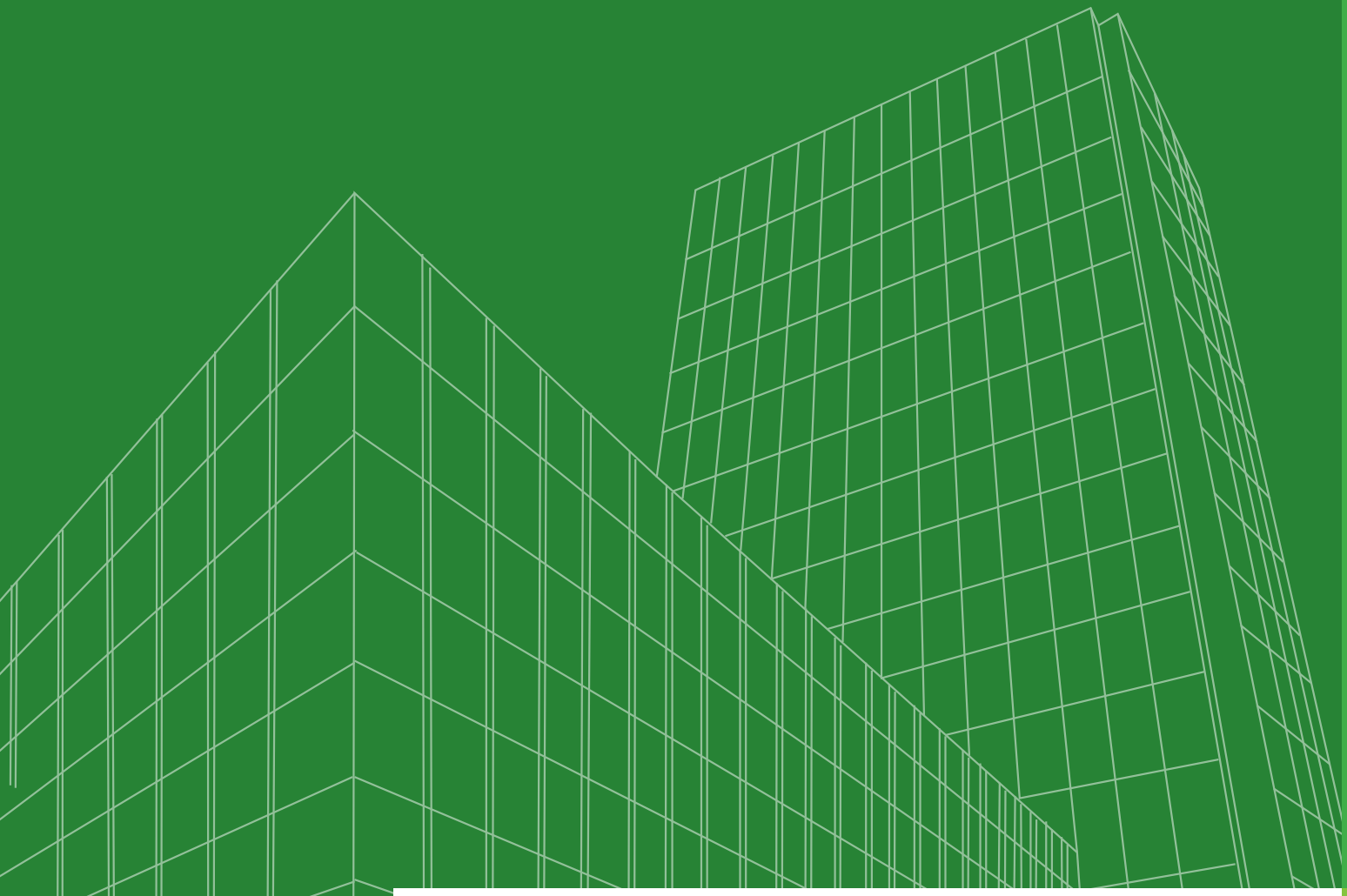
- *Satisfying client and supply stakeholder objectives and needs;*
- *Meeting social and environmental needs*
- *Recognition of available resources.*

An intelligent building starts with a good client brief and should comprise of:

- *A clearly articulated project vision and mission;*
- *A recognition of the planning, design and procurement realities*
- *Clarity about the use of a whole-life value approach.*

By using integrated design teams and user centric design buildings will have effective connectivity in terms of the occupants and the material resources.. Sustainability and a focus on people adds value. Lessons for Nature and passive architecture together with the judicious use of innovative technology can enable flexibility and an economic use of resources.

The creation of shared visions, effective teams, clear structures and robust processes ensures that the intelligent building being constructed will demonstrate the purpose for which it was conceived. Times are certainly changing so there needs to be an outlook by the project team which is long term and not just short-term. In a way this Roadmap is about change as reflected in society besides the advancements in technology that we create.



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