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Conference Chairs

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Dr Taha Elhag

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Editorial

For decades the construction industry has experienced significant pressures and challenges. This is due, in part, to its unique contributions and influence on the rest of economy and society. Many of the national reports that have examined the state of the construction industry raised concerns of the gap that have persistently existed between the expectations of the construction industry key stakeholders and the performance of the industry.

The digital revolution that is driving many economies across the globe towards industry 4 and industry 5 models and shaping corporate strategies in many sectors of the economy. This transformation of economy is creating a challenging environment that requires an accelerated pace of innovation to enable the construction industry to meet the expectation of its stakeholders. The dominant role of digital and advanced technologies could drive and motivate effort to create partnerships and alliances to exploit more challenging open innovation projects. Innovations in such projects do not only cross corporate boundaries but also traditional boundaries that have separated the different sectors of the economy. A recent example is of a major car manufacturer who opted to select a supplier from outside the automobile sector to be able to tap into technical solutions needed to improve their product, but the required knowledge and capabilities were beyond its traditional supply chain.

The pressure on the construction industry to deliver smart working, leisure and living environments would require the creation of supply chains beyond the industry's traditional supply chain and recruitment of skills beyond what existing disciplines and professions can offer. This would create opportunities for the emergence of new roles and disciplines as well create new relationships and organisational structures.

The work of the CIB Task Group 96 emphasises how to accelerate the implementation and adoption of innovation frameworks and systems in the construction sector. The ultimate goal to achieve better delivery of construction projects, healthier construction organisations, enhanced satisfaction of stakeholders and much improved industry. TG96 also aims at mapping the association between innovation theories and good practices in delivering accelerated innovation across various industries; and addressing best practice case studies.

The conference paper publications embrace various themes such as: (a) integration of data and information; (b) business models for smart BE; (c) automation and robotics; (d) the impact on culture of smart BE; (e) digitalisation of the construction sector; (f) intelligent building and infrastructure; (g) digital engineering and BIM implementation; (h) internet of things (IoT); (i) real-time monitoring and control; (j) sustainability and the environment (k) design for smart BE; (l) economics and management of smart BE, (m) accelerating innovation process (n) performance measurement; (o) agile and lean thinking; (p) resilience engineering; (q) policies and regulations.

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Track 1

Smart/Intelligent Buildings and Infrastructure

Infrastructure Developments

Research on the Adaptability Design of Smart House Based on Residential Demand

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Abstract
With the development of Internet of Things technology and the wide application of multimedia information technology and intelligent control mechanisms, great changes have taken place in people's living environment and lifestyle. In the prevention of COVID-19, higher requirements are put forward for current living quality. The application of smart home systems can help to upgrade the quality of the living environment into the intelligent era, but its intelligence is mostly reflected in the addition of unilateral multi-functions and the centralized control of the system. There is a lack of system analysis and design of residential intelligence that meets the actual needs of the users. Qualitative investigation and correlation analysis are used in this paper. Firstly, Taking the residential needs based on temporal and spatial behavior as the starting point, the functions and performance of smart home system products in the market are classified and summarized. Secondly, a correlation system is further established among residential behavior, residential needs and smart home systems. Finally, the paper takes the project of "24 • 35 housing home" in the 2021 International Solar Decathlon Competition as an example, and proposes adaptive design strategies for smart houses from three aspects: structural form, flexible space design and smart home scene setting. Based on the development of the Internet of Things and the background of new residential demand, this paper provides reference basis and optimized direction for the construction of smart homes and improvement of living quality.

Keywords
Living demand, Smart house, Adaptive design

1 Introduction

With the rapid development of society, economy, and technology, people's lifestyles have undergone tremendous changes, and there are higher requirements for the quality of the living environment. At the same time, the outbreak of the new crown epidemic has caused people to face their parents, lovers, children, work, study, and entertainment every day in their long-term home life. The needs of healthy and comfortable living environment, safety and convenience, and flexible space have never been so important. However, the existing traditional residential space in my country is difficult to respond flexibly to the dynamic changes in residential demand in the 35-year residence cycle.

During the fight against the epidemic, smart sensing equipment based on face recognition and other technologies in the community realized sensorless traffic in the community, reducing the contact within the community property; the smart elevator realized zero touch between the residents and the elevator buttons; zero-touch smart appliances based on information interaction and remote operation technologies not only effectively prevent the spread of viruses but also facilitate people's lives.It can be seen that the development of the Internet of Things technology and the wide application of multimedia information technology and intelligent control technology have promoted the iterative upgrade of the quality of living space to a certain extent. The article combines the application of residential intelligent equipment with residential adaptive design, and systematically proposes a smart residential adaptive design strategy that adapts to changing residential needs.

2 Smart house

2.1 Research status

In domestic and foreign research, there are many vocabulary similar to smart home, such as smart house, home automation, etc. Among them, the Massachusetts Institute of Technology in the United States defines intelligent housing as an adaptive and predictive intelligent service system.Its goal is to connect various information-related communication equipment, household appliances and home security devices in the home to a home intelligent system through home bus technology, and then conduct centralized or remote monitoring, control and family affairs management, and maintain the harmony and coordination between these family facilities and the residential environment."Research on Intelligent Design Strategies of Ecological Houses" (Xihang Yan 2012) proposes intelligent optimization strategies from the aspects of residential planning and design, envelope structure, building materials, ventilation, solar energy utilization and rainwater recycling. Shen Zhenjiang(2018) built an intelligent index system for smart houses through the exploration of the origin of smart houses and the discrimination of green concepts, including four aspects of respecting users, responding to climate, energy saving and water saving, and high efficiency and intelligence. From the perspective of ageing, Wu Jianxin(2017) proposed that the intelligent system should be integrated and standardized with the interior design and decoration of age-appropriate houses, highlighting the characteristics and trends of comprehensive functions, reasonable application, easy operation and access. Using the 2018 sdc entry "Habitat 2.0" as a research platform, Jiao Sen(2020) studied the realization path of his zero-energy smart house from two aspects: energy-saving technology and intelligent system. And through the energy consumption monitoring and energy management system for its sustainability evaluation research.

In the field of architecture, most researches on smart buildings are carried out from the perspective of building technology from two perspectives: the intelligent control of the indoor physical environment and the optimal design of the home energy system.There is a lack of research from the perspective of combining smart home systems with architectural design.which is based on the needs of users' living behaviors.

2.2 Smart home system

The application of the smart home system in the residential space came into being under the background of diversified and rapid development of residential demand.It uses integrated wiring technology, network communication technology, security technology, automatic control technology, audio and video technology to effectively integrate home living facilities. And using residential space as a platform, through the collection and analysis of user behavior data, to provide users with green, healthy, comfortable and efficient personalized life services.

At present, many smart home companies can be roughly divided into two categories. One is traditional home appliance manufacturers and Internet giants represented by Huawei, Haier, Midea, and Honeywell, which focus on the intelligent upgrade of large home appliances and the establishment of integrated intelligent systems; the other is represented by Xiaomi, Focusing on the introduction of smart single products, it is committed to the intelligent development of small home appliances.The research selected smart home products of Huawei, Haier, Midea, Honeywell and Xiaomi as the research subjects, and conducted research on the products launched by various manufacturers in the field of smart home.

According to the practical functions of smart home products, they can be divided into four categories, namely, security systems, smart home appliances and their control systems, environmental control systems, and health care systems (Figures 1 and 2). The article summarizes the smart products and their functions in each category, as shown in Table 1:

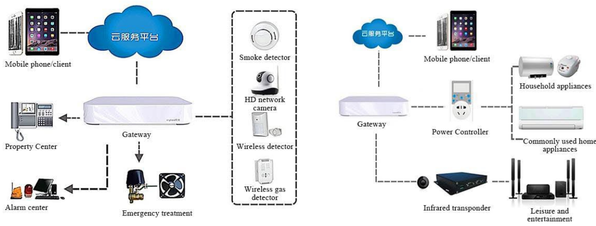

Figure 1: Security system and smart home system appliances and their control system

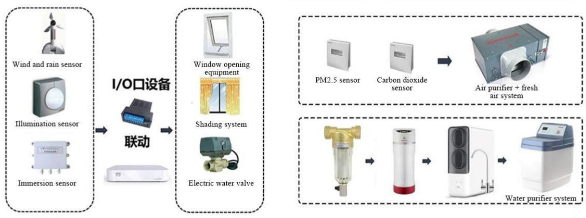

Figure 2: Environmental control systems and health care system

Table 1: Types of smart products

Types	**Products**	**Function description**
Security system	Smart door lock	Face recognition, fingerprint recognition and unlock
	Smart doorbell, cat's eye	24-hour monitoring of abnormal entrances, short video notifications on mobile phones, remote visual voice change intercom on mobile phones
	Sensor/Alarm	Temperature sensing, natural gas alarm sensor detects the danger signal of fire or gas leakage in time to warn
Smart home appliance and its control system	Smart refrigerator	Food management function: understand the internal food quantity and shelf life, and remind users of the food information in the refrigerator through the Internet and mobile phone interconnection; Intelligent control function: digital temperature control is conducive to food preservation, multiple adjustment modes to adapt to different user needs, and time-sharing to keep electricity; Entertainment functions: audio and video, games, online shopping, etc.
	Smart washing machine	Ultraviolet ray sterilization; intelligently put detergent and softener, accurately control the dosage to avoid detergent residue; automatically remind after washing, remote control by mobile phone.
	Smart kitchen appliances	Mobile phone remote control. Set up smart linkage between electrical appliances according to user behavior habits.
	Smart bathroom appliances (smart toilet, water heater, bath heater, magic mirror, smart body cleaner, etc.)	Magic Mirror: Record daily health status. When the health indicators are abnormal, it provides timely warning, pushes health advice and health recipes, and has the entertainment function of audio playback. Smart toilet: Automatically senses the flip cover, and automatically flushes away from the seat. Smart water heater: Smart linkage, and intelligently adjust the water temperature according to the user's habits.
	Smart curtain motor	It can be controlled by voice or mobile phone.
	Smart home appliances	Including smart AI speakers, sweeping robots, etc.
	Switch/gateway	Wireless induction control/network interconnection
Environmen tal Control System	Smart lighting	Centralized control to realize the lighting switch of each space in the room; intelligent dimming; set the home mode or away from home mode, one-key control

	Smart air conditioner	Actively monitor and control the indoor temperature and start the automatic cleaning function at the right time, without human manipulation; one-button setting, the air conditioner is comfortable and energy-saving.
	Sensor/Air Conditioning Companion	Sensing indoor light, temperature, humidity to link the start and stop of air conditioners or other corresponding equipment
Health care system	Fresh air purification system	Sensors are linked with air purifiers and other equipment to promote indoor air circulation, remove harmful substances such as PM2.5, dust, and bacteria in the air, and purify the air; remote operation
	Intelligent water purification system	Real-time monitoring and filtering of incoming and outgoing water quality; automatic alarm for operation failures; intelligent networking; support for remote control of flushing and standby by mobile phones.

3 The adaptability of the residence

The adaptability of the house, that is, the housing ability to adapt or respond to various changes brought about by different conditions or personal needs through the use of design forms or means under the premise of no major physical structural changes in the building(Lin Wang 2017).In "Adaptive Design of Living Space",Beisi Jia(1988) divides adaptability into functional adaptability and structural adaptability, and proposes to improve the overall quality of the residence through the design of function and space, the use of simple technology, and the structural adaptability design.Leupen(2006) believes that the durable structural system of the residence has constituted an internal variable frame system. Therefore, the formation of a polysemous space that can carry multiple functions in the basic spatial organization can enhance the adaptability of the residence.Liu Yang(2017) pointed out in his thesis "Micro-change Design of Open Houses" that the full use of multi-directional contact spaces with high accessibility can realize the flexibility of the suite. Rabeneck (2018)proposed that flexible space division equipment can be used to subdivide the space, further realize the reconfiguration of the same space at different times, and meet the changing living needs of users. For example, the 2018 IF Award Winning Works Bigger +,it meets the different needs of users in a limited space through changes in interior decoration, flexible furniture, and smart home applications.

With the widespread application of networks, smart home systems and intelligent control technologies in residences, through the linkage of intelligent devices, the ingenious use of virtual and personalized life scenes created by the environment such as sound and light,so as to meet the individual needs of users for living space.To a certain extent, this weakens the clarity of space division. On the basis of meeting the living needs, it enhances the flexibility of living space division.At the same time, this gradual approach to technological lifestyle has also improved the environmental quality and economic efficiency of the living space.

4 Living demand based on spatio-temporal behavior

4.1 Spatio-temporal behavior

The occurrence of residential behavior is directly related to residential space and time. Residential behavior permeates every part of life. Japanese resident scholar Yoshisaka Takashi classified the daily activities of the people, and proposed three types of life. He called reproduction, excretion, recuperation, foraging, and maintenance of physiological and life needs behaviors as the first life; he called housework, production, exchange, consumption and other material activities to maintain and serve basic physiological needs as the second life ; The art, entertainment and thinking activities such as performance, creation, games, and ideas are called the third life [11].

4.2 Living demand

Living demand is the need to provide convenience and security for the occurrence of residential behavior on the basis of the current living standard. With the continuous improvement of material living standards, people's living needs have reached a higher standard. The article summarizes the housing needs into four aspects: living safety, comfortable environment, convenient living, and low carbon and energy saving. In the 35-year family growth cycle of a family, the needs and desires of the occupants are constantly changing, which means that the building needs to have flexible spatial adaptability to respond to the changes in a timely manner.

4.3 Relevance system of living demand, living space, and smart home system

As the carrier, the residential space carries the occurrence of people's living behaviors, and at the same time satisfies the basic living needs. With the progress of society and the continuous improvement of living standards, people's requirements for living quality are gradually escalating, and traditional living space is not enough to meet new living needs. In the application of the smart home system, according to the needs of users in different spaces, different intelligent scenarios are created in the way of smart interconnection between products, so that the current new needs of living can be better met.(Figures 3)

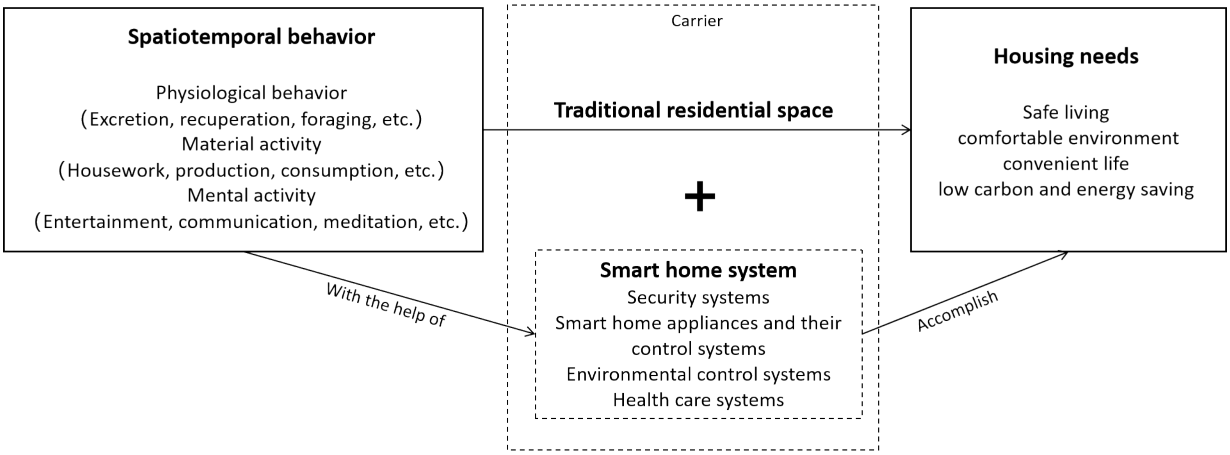

Figure 3. Relevance system of living demand, living space, and smart home system

The research uses the spatiotemporal behavior of young users in a day as a clue,and associates the security system(It is denoted by " S " in the table), smart home appliances and their control systems(A), environmental control systems(E), and health care systems(H) with the four categories of smart homes with residential behaviors and living spaces, and creates scenes, as shown in the table 2(Here we use S,A,E, and H to represent the four smart home systems).

Table 2**:** Smart home application scenario

Time	Behavior	Space	Smart home	Scene description	Advantage
6:00	Get up	Bedroom	A	The smart speaker wakes up the user on time and starts the wake-up mode at the same time. The curtain is linked and automatically opened.The smart full-length mirror will recommend suitable clothes according to the weather.The user tells the speaker that he wants to take a bath and reserve hot water...	Comfortable and convenient
	Wash	Bathroom	A	Smart speaker linkage smart water heater prepares hot water	Convenient

				according to the user's preferred water temperature. When the user comes to the bathroom to use the bidet, the exhaust fan is opened in conjunction to maintain ventilation, and the sunglasses automatically record the bidet monitoring data to help understand the physical condition. The hot water is ready,and you can start taking a bath...	
	Breakfast	Dining room	A	After washing, the coffee machine and toaster are controlled by voice, and you can start having breakfast.	Convenient
9:00	Leave home	Whole house	S + A + E	The whole house security system is activated. Lights an air conditioners are automatically turned off. The window sensor in the home automatically closes the window by sensing the weather change. Smoke detectors and alarms sense indoor abnormalities and send messages via mobile phones to inform users. It uses remote control to ensure safety and avoid losses.	Safe and energy saving
18:30	Come back home	Porch	S+E	When you get home from get off work, you can use your fingerprint to unlock the lock safely and activate the home mode. Then the lights at home will automatically turn on, and the air conditioner, air purifier and other equipment will automatically operate.	Safe and comfort
	Cook	Kitchen	A	In the kitchen, the smart refrigerator recommends recipes based on the stock of ingredients. When there are insufficient ingredients in the refrigerator, it proactively prompts users and can purchase ingredients online. Then the gas stove turns on the automatic linkage of the range hood. Everything is ready and the user can start eating.	Convenient
20:30	Casual	Living room	A + E + H	When comes to the living room after dinner, the user turns on the smart TV through voice control, and the night air purifier, air conditioner and other equipment automatically adjust the indoor state according to the weather changes...	Convenient and comfortable
22:30	Wash	Toilet	A	Before going to bed, choose your own customized bathing mode on the magic mirror and link the water heater at the same time. After the bath, you can put the dirty clothes in the washing machine. The washing machine automatically recognizes the material of the clothes and selects the appropriate washing mode.	Convenient
	Rest	Bedroom	A+S	The smart speaker receives instructions to close the curtains and lights, and turn on the security of the whole house. Gas, water, and electricity are adjusted to safe mode.	Safe and energy saving

5 Adaptable design strategy of smart house——take" 24·35 housing home" as an example

5.1 Project Overview

Solar Decathlon (SD) is a solar building technology competition initiated by the US Department of Energy with global universities as the participating units. "24 • 35 housing home" was designed as the entry of the Dalian University of Technology team under the background of the 3rd China International Solar Decathlon Competition in 2021.

"24 • 35 housing home" aims to design and build a solar smart house that can meet the needs of users 24 hours a day and the living needs of households with a life cycle of more than 35 years. The article will take "24 • 35 housing home" as an example, and propose adaptive design strategies for smart houses from two perspectives: adaptive design of living space and application of intelligent equipment, to meet the residential needs of safe living, comfortable environment, convenient living, low carbon and energy saving.

5.2 Adaptive design of living space

5.2.1 "Nine-Rectangle-Grid" space prototype

The plan extracts the courtyard space in Zhangjiakou's traditional architecture, and at the same time takes the shape of "Nine-Rectangle-Grid" space as the prototype, At the same time, the plan is based on the shape of the "Nine-Rectangle-Grid" space, using the central symmetry, modularity, unique hierarchical structure and construction (variability and flexibility) of the "Nine-Rectangle-Grid" space to cope with the changing living needs of long-term residential life. (Figure 4.5)

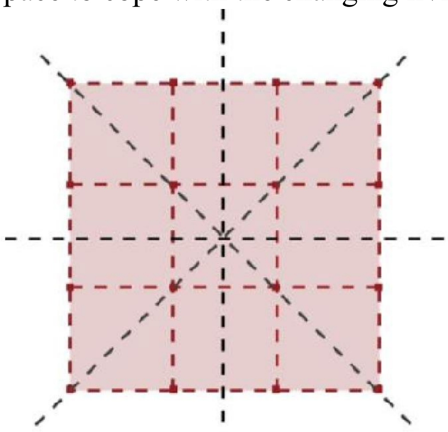

Figure 4. "Nine-Rectangle-Grid" Space Prototype space

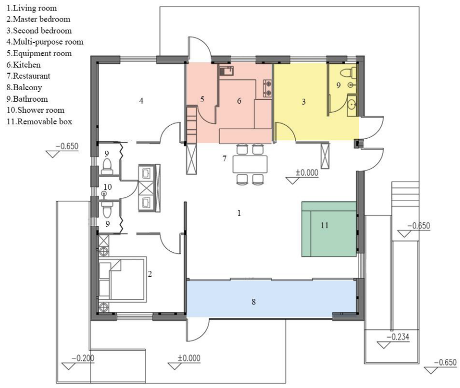

Figure5. Plan layout and flexible

5.2.2 Assembled modular structure system

The plan adopts a prefabricated modular structure system. The main structure of the project uses a steel frame structure.The whole is divided into six modules, and the living space on the ground floor is composed of two 3.6*11.5*3.35 modules and one 3.9*11.5*3.35 module placed side by side. There is a truss structure equipment layer module on the upper part, which realizes the centralized distribution of equipment pipelines and liberates the open large space at the same time.In the plane layout, all functional rooms are arranged flexibly with 3.6*3.9 and 3.9*3.9 as the basic units, forming a spatial layout with the living room as the center and surrounding rooms for other functions. On the one hand, it echoes the traditional courtyard layout of Zhangjiakou with a courtyard as the center. On the other hand, it forms a highly accessible multi-directional space layout.Through the disassembly and deformation of functional modules, it can meet the changing living space needs of the family in different periods.

5.2.3 Flexible space design

After the outbreak of the COVID-19 and knowing that it may be necessary to prepare for long-term epidemic prevention, the plan designed a flat epidemic combined with a room to respond to this special life needs. This room considers the lifestyle during the epidemic and the general period. In normal conditions, the external exit of the isolated room is closed, and the entrance streamline is unified. The bathroom can be used as a family public bathroom, the door separating the room and the living room can be opened normally, and the flexible locker can be used as a partition wall at the same time so that the room can be used as a normal guest room or study (Figure 6). During the epidemic, the external exit of the isolation room was opened, the door between the isolation room and the living room was closed, and the flexible locker moved completely separated the isolation room from the living room. The independent decontamination space and bathroom were only used by the isolation room, and the quarantined people flowed. The line is independent of the other members of the family. (Figure 7)

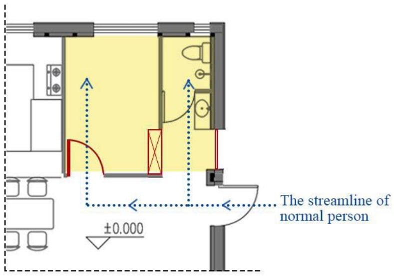

Figure 6. Spatial layout in general period

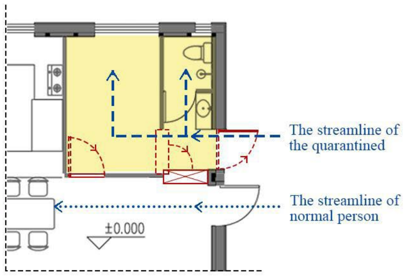

Figure 7. Spatial layout during the epidemic

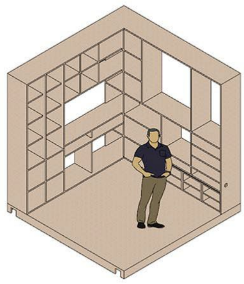

Figure 8. Flexible box

The design of the flexible box in the living room not only increases the diversity of the space, but also adds interest to the building (Figure 8). The residence must meet the changing living needs of users during the 35-year family growth cycle. The application of flexible partition walls can achieve flexible changes in the internal space layout on the basis of the unchanged residential structure frame, so as to adapt to different lifestyles at different stages of the family. In the plan layout, relatively private bedrooms and auxiliary spaces such as kitchen and bathroom are arranged along the west and north sides of "Nine-Rectangle-Grid". The living room is considered to be the center of family activities.The plan adopts an open large space form and puts a 2.4*2.4*2.4 movable box, as shown in the figure, which defines the bottom surface of the box and two adjacent sides. The two sides are given storage functions while dividing the space. In the process of the small box traveling in the space, the box and the living room boundary produce different combinations, enclosing or limiting the space effect of different feelings (Figure 9).

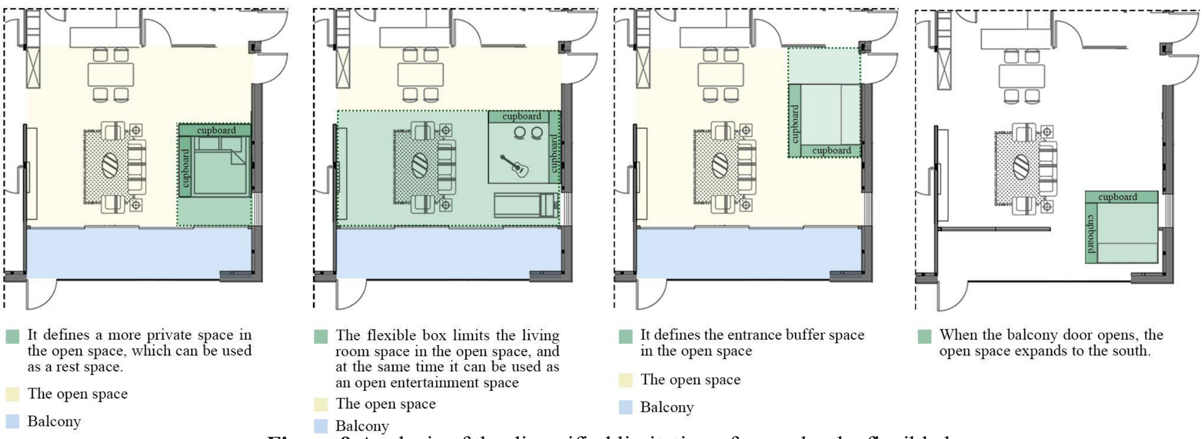

Figure 9. Analysis of the diversified limitation of space by the flexible box

The sliding double door between the living room and the balcony can be opened or closed according to the needs of use. When it is fully opened, the balcony space is released and the living room space expands to the south. When all of them are closed, the balcony can be used as an independent functional space equivalent to the Trumb wall.

The design of the kitchen space also takes into account the diversity of use requirements. When the family population structure is simple, the layout of the open kitchen and breakfast counter can be adopted. When the family population increases and there are higher requirements for the kitchen space and dining environment, the layout form of enclosed kitchen and dining table can be adopted.

5.3 Application and response of intelligent equipment

The solution is based on the correlation system of temporal and spatial behavior, living space, and smart home system, and creates different intelligent scenarios through the smart interconnection of smart home appliances,based on the user's needs in different spaces.Such as smart sleep, smart access control, smart security, smart balcony, smart lighting, smart entertainment, etc. It can cooperate with the occurrence of all behaviors after people return home, and realize the current needs for living safety and convenience.(Figure 10).

Figure 10.Smart home scene setting

The plan uses a floor radiant heating system and an air-conditioning system with independent temperature and humidity control. The air-conditioning system improves the comfort of the indoor environment by accurately controlling the indoor temperature and humidity parameters. The operating status and indoor parameters of the air conditioner can be connected to our smart phone via a wireless network. We can detect the condition of the indoor environment in real time, and easily control the air conditioner as required. At the same time, the fresh air system through air treatment, on the basis of ensuring the freshness of indoor air, it also reduces the load of the system through waste heat recovery to achieve the purpose of saving energy.

The application of intelligent equipment also helps residential houses realize intelligent control of energy.The plan further realizes green house production and energy independence through the use of solar energy.It applies a solar photovoltaic power generation system composed of solar cell components, storage batteries, charge and discharge controllers, inverters and other components(Figure 11,12), as well as the system of PVT photovoltaic photothermal integration to realize the simultaneous utilization of electrical and thermal energy(Figure 13).

Figure 11.Photos of PVT module on the roof

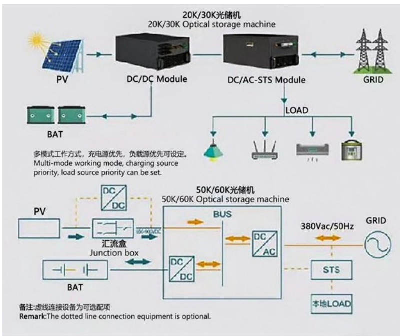

Figure 12.Photovoltaic power generation system

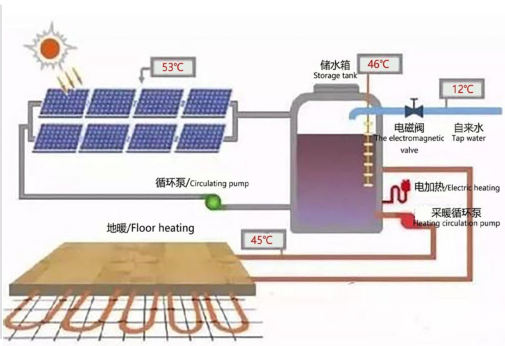

Figure 13.Photovoltaic heating system

In terms of the control of the house ’ s electricity system,the electric energy generated by the photovoltaic array is charged by the charge and discharge controller to charge the battery or directly supply power to the DC load. In the case of no sunlight or insufficient sunlight, the charge and discharge controller controls the battery to supply power to the DC load. At the same time, the off-grid and grid-connected integrated inverter is used to convert DC to AC to supply power to the AC load, while achieving automatic matching according to the end of power consumption, photovoltaic module power generation, energy storage and grid-connected grid conditions when off-grid.This further realizes the self-sufficiency of energy for the house.

The "24 • 35 housing home" project embodies the adaptive design of smart houses from three aspects: spatial structure, application of intelligent equipment and energy control. It satisfies the residential needs of the family in four aspects: safe living, comfortable environment, convenient life, low-carbon and energy-saving.

6 Conclusions and Further Research

This article is based on the background of the Internet of Things era and new residential needs, and uses the 3rd International Solar Decathlon Competition"24 • 35 housing home" as the design and research platform.The article proposes smart residential adaptive design strategies from three aspects: structural system, adaptive design of living space, and smart home scene setting based on temporal and spatial behavior. This provides a new direction for the system application of smart homes in residential spaces and the improvement of living quality throughout the life cycle of the family.

In today's rapid development of the Internet of Things, improving life with technology will become the mainstream way of life in the future.In the development of smart houses, it is also necessary to continue to track the behavior of family members in different periods, summarize the rules, and achieve iterative upgrades of living quality through the variable design of spaces, the creation of smart life scenarios, and the smart control of the home energy system.In the future promotion and application, the design can also form different sets of models through the disassembly and combination of internal functional modules,and it can be used in multi-story or high-rise residential design by adding traffic space and superimposing it vertically, thereby providing energy-saving and sustainable living environment in a high-density environment.

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Smart cities in developing countries with an emphasis on GCC countries, and its impact on expatriates amidst the COVID-19 pandemic – A systematic literature review.

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Abstract
Considering the growing concern for sustainability within the development of smart cities and the pressing need for a holistic approach to new urban developments, this study presents a systematic literature review covering the past 50 years on "Smart cities within the Gulf Cooperation Council Countries (GCC)". All relevant journal articles were analysed. Primarily, the aim was to understand the mushrooming smart cities developments within the GCC countries. The main constructs were identified from the wider literature on smart cities: challenges and drivers. These were then explored in the context of the development of smart cities within the GCC countries, and the subsequent themes and factors were mapped. Furthermore, these factors were evaluated in the context of the sizable expatriate population residing within the GCC countries and the impact of COVID-19 on them. The analysis of the articles revealed specific gaps in the literature, on smart cities within the GCC countries with respect to the expatriate population as well as the impact of COVID-19. The main findings indicated the need for further empirical studies about developing and implementing smart cities initiatives across the region, holistically, while considering the impact of COVID-19 on the expatriate population within the GCC amid this transformation.
Keywords
COVID-19, Expatriates, GCC, Smart cities.

1 Introduction

Smart cities is a network of linked systems that is meant to improve the quality of urban life (Nam 2011). Urban ecosystems or cities are complex systems with multi-levels of interactions and interdependencies (Komninos et al. 2019). Urban planning has experienced a paradigm shift due to the development of smart cities(Komninos et al. 2019). Smart cities initiatives are imperative to aid current urban deteriorating conditions such as energy shortages, scarcity of resources and poor infrastructure. Smart cities are stressed as an organic integration of systems that infuse information into the physical infrastructure. The core system is responsible for facilitating several functions efficiently by the process of collecting data , analysing it and deploying resources effectively (Nam 2011). Thus, smart cities are visualized as orchestrators of ecosystems, a larger ecosystem which consists of many smaller ecosystems. Hence to gain efficiency and sustainability especially keeping in mind, the consistently and exponentially growing population, smart cities need to integrate and govern the multiple systems through digitalization. These digital platforms are the drivers that co-create value of the ecosystems and consequently smart cities (Visnjic et al. 2016). As these smart cities are evolving to accommodate diverse and cosmopolitan populations like migrants, refugees, expatriates, international students the challenges and drivers that arise in navigating the urban infrastructure seem well-founded and overdue (Tuitjer and Müller 2021). In this study we focus on the challenges and drivers faced by smart cities in developing countries with an emphasis on expatriates within developing countries especially the GCC countries amidst the COVID-19 crisis.

Mobility of people across international boundaries as expatriates or human capital, has increased the pace of globalization (Marina et al. 2019). With increasing economic and technological competition, multinational corporations (MNCs) are known to source intellectual and human resources irrespective of their global location to promote growth. Thus, expatriates represent a vital and now following COVID-19 they are being considered the most vulnerable human capital pool for MNCs (Hajro et al. 2017). MNC's are now considering critical issues such as the organization's role in supporting employee well-being and resilience with respect to global financial crisis, pandemic situations or similar uncertain times of stress. On the flip side even the global mobile workers who have been affected severely due to the pandemic are reconsidering and re-evaluating the costs and benefits of working abroad (Cooke et al. 2020).

Prior to COVID-19, the number of migrants worldwide was estimated at a quarter billion as it continued to rise at an exponential rate (United_Nations_Development_Program 2015). These high numbers of international mobile workers (IMWs) with varying motives and movement patterns had heightened the need for an empirical as well as theoretical study on them. The impacts of the movements have a significant effect on the host and home countries of these IMWs. Studies reveal that most of these migrations are self-initiated expatriates (SIEs) while some are of assigned expatriates (AEs) (Ong 2014). Studies show that in terms of a country's total population the highest percentage of expatriates resides in Qatar, the UAE, Kuwait, Jordan and Singapore. The expatriate population in these countries is estimated to be between 40% to 80%. Of the five countries mentioned, three countries are GCC countries (ExpatChild 2013, ExpatFocus 2016). This paper further focuses on the challenges and drivers of smart cities developments within the GCC countries and its effects on the expatriate population during the COVID-19 pandemics.

2 Smart cities within the GCC countries.

The GCC countries have been experiencing rapid urbanization over the past four decades. The Gulf Cooperation Council (GCC) countries are located in the Arabian Peninsula. They constitute six neighbouring countries of Kingdom of Bahrain, State of Kuwait, Sultanate of Oman, State of Qatar, Kingdom of Saudi Arabia (KSA) and the United Arab Emirates (UAE) (Saxena and Al-Tamimi 2018). The GCC countries host a substantial foreign population as expatriates who are key players in the rapid development of the region (Shah 2013). It is estimated that 90% of the GCC population will be residing in cities by 2050 (Asmyatullin et al. 2020).

The GCC countries have embraced several smart cities agendas in their efforts to address the acute urban challenges. Nonetheless, with the emergence of smart cities in the GCC countries, there has been a gradual paradigm shift in the job market within the region (Forstenlechner and Rutledge 2010). The advent of COVID-19 has further accelerated the digitalization process in the region. These changes due to COVID-19 have affected the lives of a multitude of workers within the region. With expatriates making circa 93% of the work force in some countries like the UAE (Forstenlechner and Rutledge 2010, Shah 2013), there has been mass scale deportation of staff while in a few sectors like the education sectors there has been a shift to remote working (Al-Youbi et al. 2020). Research has been slow in grasping the impact of smart cities initiative on the expatriates within the GCC countries amidst the COVID-19 pandemic.

3 Methods

This study adopted a systematic review of scholarly research on smart cities within developing countries, focussing on the GCC countries with emphasis on the impact of the COVID-19 pandemic on expatriates. A systematic review is a form of meta-analysis wherein the fragmented information is collected, investigated and summarized to evaluate and effectively interpret all available research relevant on a particular research question or topic area or phenomenon of interest. It was observed that each study in this rapidly developing area was limited in its scope and reflective of diverse findings posing a risk to integration of findings among researchers (Briner et al. 2009). The time span for all databases evaluated for this study was from 1970 until the present year 2021. It included all journal articles, reviewed papers, research reports, book chapters, conference proceedings and dissertations, published in the English language. As a positive assessment tool, systematic reviews are an effective exploratory methodology as they bridge the "research-practice gap" (Rousseau 2006).

3.1. Definition of research questions

A set of research questions was defined within the first stage of the systematic review. The questions were devised so as to provide the required overview of the current research on smart cities within the developing countries with an emphasis on the GCC countries.

- Q1: What are the Challenges faced by Smart cities initiatives within the GCC countries?

This question reveals the concerns of sustainably developing smart cities considering the high shuffling expatriate population. The barriers were traced from the various domains of governance, environmental, societal as well as technological.

- Q2: What are the Drivers for Smart cities initiatives in the GCC Countries?

This question was designed to gain a comprehensive overview of the main drivers in relation to the development of smart cities within the GCC countries.

- Q3: What are the effects of COVID-19 on expatriates and measures taken to curb its spread through smart cities applications within the GCC countries?

Understanding the barriers and problems that expatriates faced during the COVID-19 pandemic is beneficial in deciding where future research and development efforts should be directed. A clearer picture of the pressing challenges and risks can be obtained through an analysis of this situation.

3.2. Conducting the search

The phase two involved a data collection stage, outlining the methods used to undertake the systematic review. Since a systematic review is a collaborative effort, the process designed should reduce the researcher bias (Briner et al. 2009). The search used included prominent databases such as- SciTech Premium Collection, EBSCOhost, Web of Science, Nexis Advance UK, Taylor and Francis, Springer, Wiley, Emerald Journals, Business Source Premier amongst other search sources. The main search terms used were "smart cities" and "developing countries" as a single construct, "GCC", "COVID-19" and "expatriate". These terms were searched for in the title, abstract as well as entire paper.

3.3. Screening and selection of relevant articles

The eligibility criteria for selection of literatures were based on their field of study, topic, publication status, publication year, research method, database and language (Lim et al. 2019, Moher et al. 2009). The authors also used the phrase searching function and the Boolean operator "And" to combine the keywords in their advance searching process. The inclusion criteria included mainly peer reviewed journals. The selected relevant articles were then further screened by examining their titles and abstracts as well as results and methodology sections to match the criteria of the study. Articles that provided insights on urban sectors such as governance, economy, mobility or technology related to smart cities initiatives were included. Theoretical, empirical, qualitative or quantitative research were also included. The search further narrowed down on mapping existing literature on smart cities within the GCC. Thus, articles from any other countries or regions were excluded. Several journal articles were excluded for the following reasons: articles without full availability, articles not available in English, duplicate articles, irrelevant to the topic and posters.

Our initial search of the databases in May 2021 yielded 1,813 peer reviewed articles with the search words “Smart cities” and “developing countries”. On further narrowing the search with the addition of the word “expatriates” the number reduced to 19 articles. These 19 articles were reviewed in depth for their relevance to the topic. It was revealed that 10 of the 19 articles were focused on the GCC countries. This led to an in-depth search of systematic literature reviews on smart cities in the GCC countries.
In the next round of revisions, the search included the words “systematic literature review” , “smart cities” as one construct and the addition of the words GCC. The peer reviewed articles identified were 132 of which several were deemed irrelevant as there was a casual mention of the word GCC or “ smart cities” in the reference and the main paper had no relevance to the topic. The selected articles were analysed to ensure the quality and relevance of the academic literature included in the review process then the exclusion criteria were carried out. In the final analysis 20 journal articles were found relevant. Of these, there were 2 articles that were unavailable and were excluded from the study. After further filtration of the journal articles 11 more articles were removed from the study following a detailed assessment of each article on the aforementioned inclusion and exclusion criteria. Finally, the remaining were 7 core relevant articles. The PRISMA method was adopted for the analysis of the literature exclusion and inclusion criteria at every stage.

4 Findings and Discussion

4.1 What are the Challenges faced in the development of Smart cities initiatives within the GCC countries.

4.1.1 Governance framework management

There is a concern to develop cities, sustainably that are aligned with the goals laid down by the United Nations in their SDG 2015 (Sustainable_Development_Goals 2016). The GCC countries are highly urbanized. The current growth rate is such that by 2050 it is estimated that 90 percent of their population will be living in cities as projected in Table 1.1 (Asmyatullin et al. 2020)

Table 1.1
Urbanization rate in GCC countries

Country	2015	2050
Bahrain	89%	93.2%
Kuwait	100%	100%
Oman	81.4%	94.9%
Qatar	98.9%	99.7%
Saudi Arabia	83.2%	90.4%
U.A.E.	85.7%	92.4%

Considering that most of this population is migratory and expatriate it is a challenge to manage the public administration and governance of the states. A major segment of this population is represented by low-income workers, followed by middle-income technicians and professionals. The development of this region depends on this shifting population of immigrant people (Khalaf and Alkobaisi 1999). Consequently, managing this shuffling population can be a daunting task. To ensure the smooth running of the state it is essential to improve the interaction of the government with the citizens and residents. There is a responsibility to efficiently and swiftly provide services that can facilitate the smooth transition of this migratory population to adapt to the new place. This is one of the main challenges that has accelerated the transformation of several cities within the GCC countries towards smart cities initiatives. Involving ICT by way of e-government applications and technologies would be conducive to the smooth management and organization of these fast growing cities (Al-Nasrawi I 2015).

4.1.2 Technological challenges or barriers

There is the need to source the required talent to achieve the smart cities goals as it is not easily available locally. Hence the need to develop knowledge-based cities within the region. Furthermore, there needs to exist trust and openness between the private and non-state actors and the government for the smooth development of smart government. This system is a paradigm change for the prevalent traditional governments models presently functioning within most of the GCC countries (Samad and Azar 2019). The implementation of smart governance infrastructure needs to incorporate collaboration along with communication and data exchange, service and application integration, accountability, transparency that can harness participation and partnership (Joshi 2016). Technological challenges encompass the operation cost, cyber security and privacy concerns (Ciborra and Navarra 2005).

4.1.3 Natural and built environmental considerations.

Another impediment faced by smart cities is the requirement of regular assessment of environmental sustainability performance (Egilmez et al. 2015). Efforts need to be made to develop strong eco-human symbiotic bonds through sufficient green spaces and sensitivity to the environment. Adverse effects which can be due to uncontrolled constructions and development along with the effects on the environment caused by uncontrolled human activity such as traffic, manufacturing, pollution of air, water, earth have to be mitigated. The smart cities implementation needs to incorporate a control on the carbon footprint generation within the cities through its design and maintenance plans (Giest 2017). Likewise, smart urban development needs to incorporate provisions for failure management. Pandemics, tornados, earthquakes and other similar natural disasters can wreak havoc with network unavailability accompanied by infrastructure breakdowns. The challenge lies in identification of recovery strategies and mechanisms that can revert normalcy to cities operations with minimal effects to operational efficiency and within controlled cost (Silva et al. 2018).
Furthermore, the surge in greenhouse -gas emissions (GHGs) due the regions high dependency on its hydrocarbon reserves (Malik et al. 2019) triggers the need to develop sustainable strategies for energy generation and distribution, urban planning and the construction of eco-friendly (green) buildings, water and transport management within the region. (Samad and Azar 2019). Moreover, setting the long-term goals of each specific city and integrating a holistic plan towards its development adds to the complexity of the task in hand (Joshi 2016, Samad and Azar 2019). For example, the Kingdom of Bahrain has implemented a number of smart cities initiatives. However, these are the efforts of the several private organizations or specific public sectors and are lacking the support of a national conceptual framework. An economic strategy at the national level is recommended so that a comprehensive framework can be agreed upon for a holistic development and smooth facilitation of the cities' transformations. This is a non-linear process requiring strong support of government policies (Samad and Azar 2019).

4.1.4 Societal challenges

The social barriers faced by the GCC countries includes inadequate collaboration between the research, development organizations and the government, poor understanding of the impact of smart technologies amongst the administration and citizens, not enough citizens' engagement, digital divide among citizens and other residents (Mansour Naser et al. 2016).

4.2 What are the Drivers for Smart cities initiatives in the GCC Countries.

4.2.1 Diminishing hydrocarbon reserves leading to growth by economic diversification.

The GCC countries geographically lie in the "global sunbelt" which is richly endowed with solar radiation and wind energy. Despite this huge potential for renewable energy, the GCC countries still depend primarily on their reserves of hydrocarbons (Alnaser and Alnaser 2011, Griffiths 2017a). Their major energy policies are driven by the bounty reserves of 52% globally proved oil and 42% of gas reserves and further accompanied by access to cheap subsidized energy to its citizens (Poudineh et al. 2018). Each member state within the GCC countries has ambitions and targets for renewable energy although deployment to date is minimal. Most of them lack the required grid infrastructure or the institutional capacity to undertake the risks and uncertainties involved in their deployment (Poudineh et al. 2018).

The hydrocarbon reserves that the GCC countries strongly depend on, are diminishing. Hence there is a need for economic diversification into other resources for growth. the GCC countries lack a consolidated policy framework to advance their development. Therefore, there is a need for a well-articulated policy for utilization of renewable energy in each member state (Malik et al. 2019). There are concerns of sustainability of the environment, long-term uncertainty of fossil fuel markets, unstable price of hydrocarbon reserves and fears of fiscal instability which are amongst the major drivers to implement smart measures of sustainability (Mohandes et al. 2019, Poudineh et al. 2018). Due to the increasing population, there is sharp increase in the demand for clean portable drinking water. The desalination of water in the region is heavily dependent on energy consumption, further pushing the need to find alternative renewable energy technologies. There is a huge demand for commercially viable alternative sources of energy such as solar or wind energies within the MENA region(Gazzeh and Abubakar 2018). Furthermore, there is the global pressure to initiate a low-carbon economy to demonstrate the commitment of the GCC countries to the 2015 Paris agreement (Baruch-Mordo et al. 2019, Kern and Rogge 2016). All the above in addition to environmental concerns and the need to achieve significant self-sufficiency within the renewable energy sectors are the major drivers for developing smart cities initiatives in the region (Griffiths 2017b)..
The development of smart cites is also associated with the creation of a knowledge-based economy. It is crucial to increase the public expenditure of education, which is reflected in the graph in figure 2, that projects the expenditure of UAE and Saudi Arabia on education is significantly high. Statistics show that this investment is more than 20 % higher than developed countries such as UK, Germany and the United States (Alateyah S 2013, Asmyatullin et al. 2020).

Figure 2
Public expenditure of education

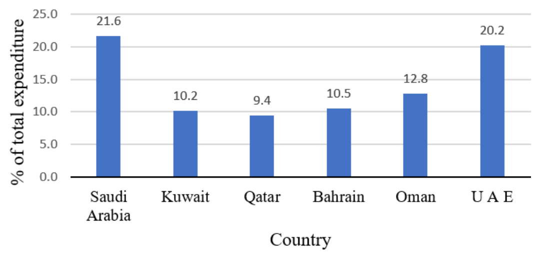
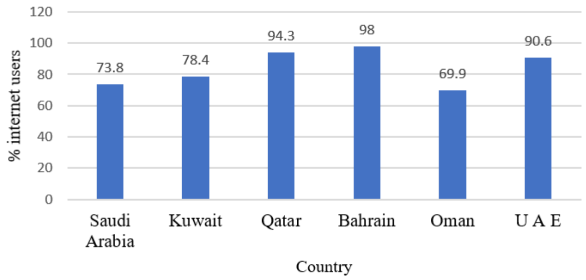


Figure 3
Internet Users,%



(Asmyatullin et al. 2020).
Similarly, along with education, the public expenditure on R & D is another critical driver for smart cities development especially in sectors such as Business, government and Universities. Within the GCC countries the expenditures on R& D are less than 1% of the GDP as compared to countries like South Korea which spent 4.7% on R&D in 2018 (Asmyatullin et al. 2020, Tim Callen 2014). The use of internet by the citizens along with the individual level of computer skills of its citizens is again a determining factor in the smart cities planning. The GCC countries score high, with more than 90% of population active internet users. As shown in figure 3 in Qatar, UAE and Bahrain. Saudi Arabia, Oman and Kuwait have an increased percentage of internet users which is estimated 1.75 times higher than the world average (Asmyatullin et al. 2020, Alateyah S 2013). All these are the contributing drivers for smart cities developments within the region.

4.3 The Impact of COVID-19 on expatriates in the GCC

4.3.1 The effects of COVID-19 on the GCC countries

The World Health Organization (WHO) declared the outbreak of the infectious disease COVID-19 on the 11 March 2020 (World_Health_Organization 2020). Amongst the GCC countries, the first cases to be reported, were in the last week of Jan 2019. All six GCC states synchronized their policies on enacting travel bans between March 14 and March 18. They were cohesive in following similar rules to curb the

COVID-19 pandemic such as controlling thesmart mobility of foreigners, cancelations of work visas and a fungibility policy for foreign workers to regulate the size and status of the expatriate population (Young 2021).

4.3.2 Measures taken to curb COVID-19 through smart cities applications.

To cope up with the challenges of the pandemic, businesses witnessed an escalating growth in the use digital technologies in various sectors of health, finance, education and retails (Zulqarnain et al. 2020). This digital transformation facilitated the generalization of online payments and online medical consultations as well as the implementation of several government policies and decisions (Ben Hassen et al. 2020, Zulqarnain et al. 2020). Provision was made for free-of-charge healthcare to patients and the launching of COVID-19 active screening. Thus, proactive, quick and stringent measures were systematically adopted by the health and government officials within the GCC. The smart cities initiatives played an important role in successful curbing the spread of the disease. There were numerous awareness campaigns launched in multiple languages and through various forms of media to increase the public awareness of the COVID-19 infections and provide up to date information, catering to the various nationalities and multilingual expatriates residing within the GCC countries (Thamir et al. 2020).
Due to the COVID-19 outbreak, millions of expatriate workers within the GCC, were quarantined (Ajami 2020). There were significant implications on economic growth, oil prices fell, international cooperation, government policies as well as the investments suffered, due to the various lockdowns across the globe (Elliott et al. 2020). Transport and travel restrictions were adversely affected. Numerous industries such as aviation, retail, hospitality, tourism in addition to crucial sectors with complex value chain linkages such as electronics and automotive products suffered huge losses (WTO 2020).

4.3.4 Effects of COVID-19 on Expatriates

The COVID-19 triggered a series of policy shifts with more "nationalization" of jobs, flexible visas, new taxes and fees for foreign workers and vast purges of workers from the construction, aviation and hospitality industries. Several expatriates were left stranded and unemployed. Approximately 700,000 expatriates from Saudi Arabia had been laid off, to go back to their homes in the neighbouring Arab countries and South Asia. The unemployed foreign workers were expected to return to their home countries within a 30-day period to ease the burden on the governments. The legal responsibilities of firms and organizations towards expatriates also had been changing during the pandemic period, making it easier to lay off foreign workers, reduce their salaries or force employees to take paid or unpaid annual leave. The government had been providing minimal support to sustain small and medium sized businesses, although they were extending basic health care to expatriates. The losses sustained by the major employers in the region were the state-owned airlines, logistics and major contracting firms, many needing major recapitalization to survive. It was difficult to continue functioning with the same number of employees as business were fast dwindling to minimal capacities. The social impact of the pandemic on the transmigratory expatriates was calamitous as they were stranded without jobs, borders were closed, and flights cancelled for months. Furthermore, they were quarantining in a foreign country away from family support (Young 2020). The job layoffs did not affect the national citizen as majority of them worked in the public sector where there were no job losses (Young 2021). There was a decline in GDP growth rates and economy resulting from these unstable oil prices, suspended flights, shutdown of tourism and hospitality and uncertainty regarding the healthcare after effects of COVID-19 (Ajami 2020). Economic recovery from the COVID-19 pandemic within the GCC countries, now, relied on government social support, public health, foreign direct investments, access to international debt capital markets and serious fiscal consolidation. They are faced with a situations of plentiful oil supply versus less oil demand, presence of competitive renewable energy options and investors who are discerning consumers of carbon-intensive products (Young 2020). The COVID-19 situation has increased the uncertainty regarding expatriate jobs in the GCC countries. Simultaneously, there have been several protective measures by the governments, numerous individuals, communities and charities who have been involved in helping the staggering numbers of less privileged people in the GCC countries, those that were disrupted socially and financially (Saeed et al. 2020)

5 Conclusions and Further Research

The purpose of this paper is to provide a systematic analysis of the literature that addresses smart cities from the perspective of expatriates and the impact of COVID-19 in the GCC countries. Such an effort has not, to date, been undertaken. The topic of expatriates within the GCC countries as well as that of smart cities developments within the GCC have been receiving growing attention as illustrated in the increasing number of papers every year. However, the literature could not find any research linking smart cities and expatriates in the GCC countries. Furthermore, there is no empirical data on the impact of smart cities initiative on the expatriate population during the COVID-19 pandemic. Therefore, the objective of this study was to understand the literature covering the topics of smart cities, expatriates and COVID-19 within the context of the GCC countries. and offer suggestions regarding the best directions for future research.

The main conclusions of this study indicated that further research is needed to evaluate the impact of the smart cities' initiatives on expatriates in the GCC with an emphasis on the transformation into green economy. It is worth noting that a significant percentage of the expats in the GCC region are labourers in the construction sector and other service sectors. Future research should investigate empirically the impact of smart technologies as well as the ability of those humble expatriates in adapting amid this transformation. Furthermore, the field would benefit from more in-depth studies and data on the provisions of smart initiative for failure management, network unavailability or infrastructures breakdowns during desert storms, dire weather condition or pandemics. There is a need for the identification of recovery strategies with minimal impact on operational efficiency yet within controlled cost with emphasis on the low-wages expatriate communities.

Indeed, it is quite exhaustive to examine a topic such as smart cities developments which covers a plethora of research areas. This research can help practitioners to better understand the smart cities initiatives with respect to expatriate population in times of emergency such as the COVID-19 pandemic in the context of the GCC countries and assist researchers to orient their efforts in a manner that is coherent with past developments and future perspectives. This paper contributes to evaluating a gap in research on the smart cities within the GCC countries and the impact on its expatriate population amidst the COVID-19 pandemic.

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Creating Smart Cities: A case study of Energy Hub for effective energy management

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Abstract

One of the most critical challenges facing humanity in the twenty-first century is the scarcity of energy. These challenges appear in many different fields, including energy supply, exchange, and consumption. The energy scarcity is due to population expansion, growing worldwide demand for energy, natural resource shortages, and environmental concerns. Furthermore, scarcity of energy requires the growth of renewable energies and energy efficiency; it is considered a top priority for all governments and organisations to resolve.

The energy efficiency of buildings is an important concept when discussed in the context of smart cities. Buildings arethe largest energy consumers since the building sector is responsible for 40% of energy consumption. Recent developments in machine learning within a big data environment have created opportunities for more effective management of energy use in buildings. Managing buildings energy consumption effectively through a real-time measuring process enables the economy to move away from a linear consumption model to a circular model. This will solve the problem of late notification of energy-saving measures failure and allow quick rectification to bring the energy management system back to high performance. The size of the energy hub is unlimited; it can be a single home energy system or a city-wide energy system.

This paper will present a case study on developing a smart energy hub called Hub grade 4 that relies on connected products and artificial intelligence. Hub grade 4 is the name of Enova by Veolia smart energy hub; Enova is MENA regional leader in integrated energy and multi-technical services delivering performance-based energy and facilities management solutions. Hub grade 4 provides an innovative approach to successfully implementing energy efficiency improvement using artificial intelligence and real-time data. The case study will explore how energy management can utilise real-time data to be efficiently used by residential, commercial, and industrial clients. This paper concluded and highlighted lessons learned from the successful implementation of innovative energy management, which relied on a dedicated organisation, effective adoption of digital technologies, and embracing new business models, resulting in power savings of 254 million kW and water savings of around 3 million cubic meters, as well as financial savings of about 138 million AED in 5 years since hub grade 4 started operations its first energy-saving contract in 2017

Keywords
Energy Hub, Smart Cities, sustainability, energy management

1 Introduction

While Cities utilise 78 percent of world energy and generate 60 percent of global greenhouse gas emissions, it occupies only 2% of the earth's geographic area (UN, Cities& Pollution 2018). As urbanisation rises from 55 percent of the world's population to 66 percent by 2050 (UN, world organisation prospects,2018), its environmental impact will increase. Improving resource efficiency at the municipal level would acquire more environmentally sustainable solutions and aid in the transition to a more sustainable future.

One of the most important prerequisites for next-generation smart cities is a reliable, efficient, and low-carbon source of energy (Edward et al., 2019).

The notion of a smart city has gotten a lot of interest in recent years because it uses digital technologies to develop service delivery and energy optimisation. Smart cities use different sensors to capture digitised data and provide information that is then used to manage systems and efficiently optimise assets' performance. Data about equipment, buildings, people and different type of assets are treated and analysed to enable traffic systems, energy supply, water distribution networks, waste collection, law enforcement agencies, information systems, residential communities, shopping malls, commercial buildings, hospitals, airports and other community services to be monitored and managed (Sanguk el. at 2019).

A smart energy city is a city that optimises energy consumption and has a well-planned energy management system, and reports energy-saving achievements properly. (Nielsen et al. 2013) the sustainable smart energy city (SSEC) idea provides comfort, energy-saving and wellbeing to its people through systematic and continuous improvement of energy management systems using new technologies to develop energy consumption. (Sanguk et al. 2019).

This call to build sustainable smart energy infrastructure within the city will allow for continuous enhancement of energy consumption and safe and pleasant living, and a speedy and cost-effective metropolis built on smart infrastructure. (Shahidehpour et al. 2018).

A smart energy city's long-term viability necessitates the intelligent and systematic deployment of technologies, as well as an examination of each of the city's assets. In the energy business, sustainability refers to the effective use of energy in general, but it also refers to the development and deployment of new technologies to enable efficient operations (Park et al. 2016).

2 Literature Review

2.1Energy Hub Concept

The Energy hub concept was first established as a result of the VOFEN project; the research team from ETH Zurich's Power Systems and High Voltage Laboratory proposed the EH concept as part of the project "a vision of future energy networks (VOFEN).Using a greenfield methodology, the project attempts to picture future energy systems in the long term (20–30 years) (Geidl et al., 2007).

It was defined as an interface between consumers, producers, storage devices, and transmission devices in various ways in handling one or more carriers directly or via conversion equipment (Mohammadi et al. 2017).

Traditional energy supply systems (for example, electricity networks) feature a hierarchical structure in which an energy carrier's generation, transmission, scheduling, and administration are primarily the responsibility of a hierarchical structure (Geidl et al., 2007).

As a result, one of the primary advantages of an energy hub is the efficient use of multi-generation (co, tri, or poly-generation) systems to maximise energy efficiency while minimising emissions and costs. (Mohammadi et al. 2017).

Synergies between different types of energy give a huge opportunity for system enhancement. Aside from modern information technology's capabilities, state-of-the-art and new and looming energy technologies, such as fuel cells, are considered.

Energy hub has a good opportunity to reduce energy consumption by optimising and switching between different technologies to match energy usage. also, the energy hub can efficiently use resources, improve efficiency, reduce cost, and minimise carbon emissions. (Mohammadi et al. 2017) Energy hubs can be applied for different sectors; it can be applied for residential, commercial, and also industrial including shopping centres, housing complex, educational complexes, hospitals, hotels, small and large factories, airports and even individual residential or offices buildings, it can be applied for the limited geographical area or an entire city. The size of the energy hub is beyond any limitations; it can be a residential unit or shopping centre, or the whole city.

Energy hubs can be divided into two types, micro hubs and Macro hubs, depending on the type of control, the objective of consumers and consumption pattern; for example, the consumption pattern in residential is during early evening hours while industrial is almost constant. (Mohammadi et.al 2017) The micro hubs are divided sector-wise into residential, commercial, and industrial. The macro hub is a combination of several micro hubs. There is a need to exchange a huge volume of data in the macro hub, where we need smart technologies to process these data.

2.2 Micro Energy Hub

Based on consumption, the micro hub can be in 3 groups of energy hub and will be discussed herein details

2.2,1 - Residential Energy Hub

As per EIA yearly report, US buildings consumed 40 % in 2020, the residential consumed 22% and 18% of the energy consumed by commercial buildings, for several reasons like long transmission network and huge distribution, weak management of consumption. (eia 2020).

For that reason, the energy hub will be a good solution for the residential sector; using PV, heat pumps, led lights, and solar collectors will be a good method to optimise energy usage. Due to rising energy prices, environmental concerns, growing demand for electricity, and network instability. These issues necessitate the most efficient energy generation, storage, and consumption solutions. (Enrico et al 2009)

For all these reasons, the options like energy hub and energy management systems look like good solutions. implementing this model for energy management in real-time for energy consumption, production, storage and conservation benefit both consumer and distribution company; this model was applied on real houses in Ontario, Canada, gives 20% energy saving and on-peak demand of the consumer energy consumption it gives more than 50% reduction. (Isha et al., 2015).

2.2.2- Commercial Energy Hub

Total energy consumption by the residential and commercial sectors includes end-user consumption and electrical system energy losses associated with retail electricity sales to the sectors. When electrical system energy losses are included, the residential and commercial sectors accounted for about 22% and 18%, respectively 40% combined of total US energy consumption in 2020 as per the EIA report (EIA 2020).

As a result, existing buildings performance is far from optimal, and there is significant room for energy savings in this sector. Business structures are emblems of economic progress, and the construction of high-rise buildings has become a competition between industrialised and emerging countries. (Mawed et al. 2020).

Increased efficiency in commercial buildings is an essential move toward more optimised energy consumption with less impact on the environment. Several factors can influence a building's energy efficiency, and as a result, various strategies can be utilised to increase it.(Mohammadi ,et.al 2018).

In commercial buildings, the integrated energy management system is essential for effective scheduling, successful participation in demand-side management programs, and gaining the benefits of smart grids.

In a study applying energy management system to a commercial building, aiming optimal operation of the building services lowering energy costs, boosting efficiency, and lowering emissions. The findings revealed that by merging several technologies and managing the building's energy systems as a whole, peak demand and energy expenditures were reduced, while carbon emissions were reduced. (Mohammad et al. 2012).

As a result, by controlling information such as weather forecasts, production, and demand patterns, the Building energy management system can determine the best performance of the building's energy systems. This integrated management results in lower costs, fewer peak hours, less environmental effect, and successful involvement in disaster recovery programs. (Mohammad et al. 2012).

Thermal and lighting loads are two important loads in commercial buildings. The main energy consumers in commercial buildings are heat loads, particularly air conditioning systems, heating and cooling systems, which significantly affect peak load (Jesse et al., 2011).

The air conditioning load(HVAC) is greatly influenced by the weather, particularly the ambient temperature. In addition, weather conditions, such as solar radiation, have an impact on the lighting burden. As a result, weather conditions have an impact on the performance of commercial buildings. (Dimitris et al. 2014).

In commercial buildings, the usage of distributed generation units such as cogeneration units like combined heat and power, wind turbines, and fuel cells are on the rise. The integration of distributed generation units, particularly Renewable energy, into commercial buildings poses new issues and/or opportunities for their management, indicating that the energy hub model has excellent potential.

In conclusion, several strategies have been employed to lower the commercial sector's energy expenses and emissions due to increased energy expenditures, environmental concerns, and the need for energy efficiency.

These strategies can be successful when used in conjunction with an integrated management system like building an energy management system. Finally, in the framework of an energy hub model, modelling and achieving building energy management systems in the commercial sector while taking into consideration energy storage systems, multi-generation systems, Renewable energy systems, demand-side management is possible. (Mohammadi et al. 2018)

2.2.3 Industrial Energy Hub

The world's largest energy consumption sector is the industrial sector, and it is considered a major source of greenhouse gas emissions. Energy demand in the industrial sector is steadily increasing as a result of increased industrialisation, the creation of new industrial countries, and rising consumption in developing countries.

According to the IEO2019 reference example, the industrial sector consumed 50 percent of world energy consumption in 2018, and its energy demand will increase by an average of 30 percent per year from 2018 to 2050. (iea 2019).

Aside from CO2, the industrial sector contributes significantly to the emissions of other GHG gases such as carbon monoxide (CO), sulphur dioxide (SO2), and nitrogen oxide (NOx). Therefore, this sector's energy efficiency and emission reductions have a significant impact on climate change mitigation.

Energy audits and waste heat recovery are two of the most basic methods for improving energy efficiency and lowering emissions in the sector. The energy audit will find potential for optimisation and energy savings, the use of technological approaches such as variable frequency drives for motors, heat recovery wheels, cogeneration, energy-saving equipment, and so on are examples of the first instance. (EA Abdelaziz, 2010)

Also, Energy Management System, which determines energy usage when and where it is required. The energy management system aims to reduce energy expenditures and environmental impact without affecting the quality or quantity of delivered services and products (Mawed et al., 2014).

Including Developing energy policies at the governmental level to encourage factories owners to improve energy efficiency, subsidies for the integration of renewable energy sources, rules and deterrent penalties such as carbon taxes, and employee penalties are all examples of government policies to encourage public sector and private sector to improve their energy efficiency; All these can be considered as efficiency enhancement for the industrial energy sector.

It can be said that the need for an integrated energy management system will improve energy efficiency in the industrial sector within an industrial energy management hub. (Nicolás and José 2013).

2.3 Macro Hub

When micro-energy hubs are combined, a concept known as a macro energy hub emerges, in which a group of energy hubs can be operated and managed in a coordinated manner. A residential community, an urban neighbourhood, commercial buildings, an industrial facility, a town, or even a whole city can all be considered a macro energy hub. (Mohammadi et al. 2018).

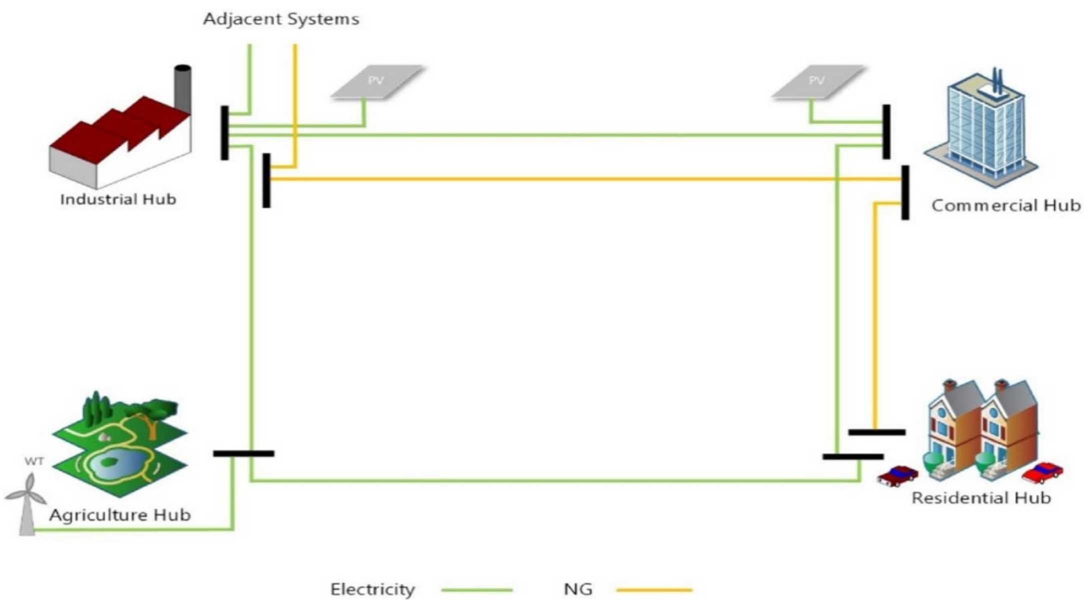


Fig1 Schematic representation of a macro energy hub. (Mohammadi, et. al 2018)

This is only a simplified graph of how electricity and natural gas networks connect four different types of consumers: residential, commercial, industrial, and agricultural (here, we treat farms as part of the industrial sector). Various networks can also connect various consumer sectors.

Increased system efficiency and renewable energy penetration and reduced waste, less environmental impact, and less fossil fuel usage are all benefits of this integration.

The energy hub idea can be used to represent such systems and provide improvement opportunities. The interconnection of infrastructures such as electricity, gas, and district cooling and heating networks is increasing as multi-generation technologies improve; Fig 1 shows the macro energy hub model. the energy hub serves as a link between various energy systems.
This integration can be thought of as a macro-energy hub.

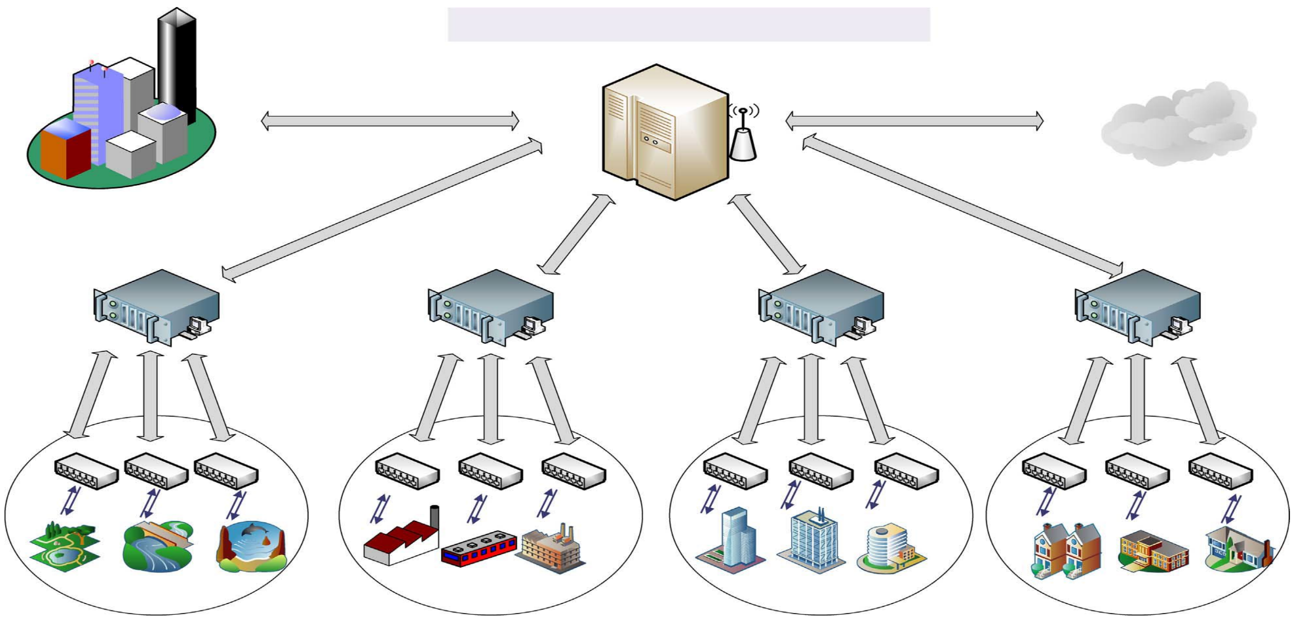


Fig 2 Schematic representation of a centralised macro energy hub management system. (Mohammadi ,et.al 2018)

One common centre is usually used for small-scale systems, but it is incapable of dealing with large-scale systems. Processing and exchanging information becomes more complex as the amount of variables and information to be processed grows, the computing load grows, and achieving the optimal solution in an optimisation problem becomes more difficult. Fig 2 illustrates the centralized hub management system.

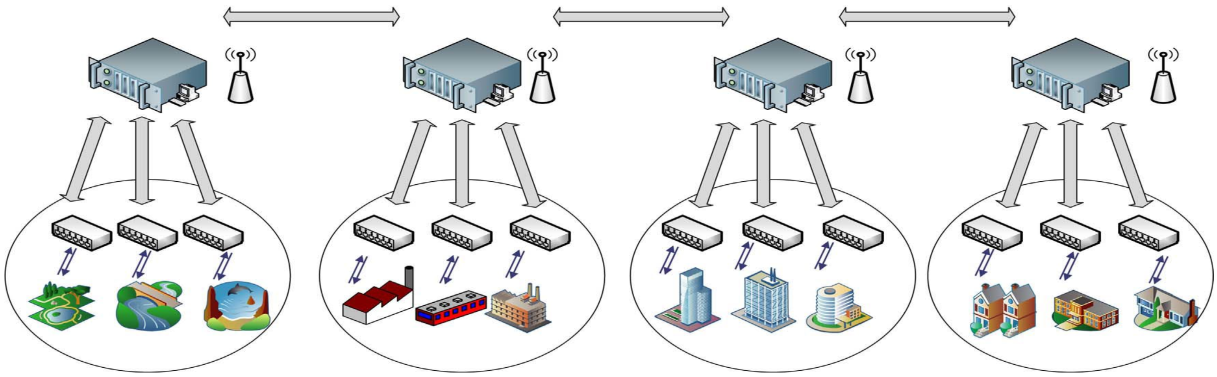


Fig 3: Schematic representation of distributed macro energy hub management system. (Mohammadi ,et.al 2018)

The optimisation issue is broken into multiple subproblems and then addressed in the same way. Compared to a centralised schema, the dispersed method has several advantages. First, the distributed mode is more reliable because, in the event of a failure in the control regions or performance faults, just that area would lose control. At the same time, the remainder of the system would continue to work at its best, Fig 3 showing the connection of several Macro energy Hub.

The main advantage of the macro energy hub is that it allows for the coordinated control of many consumers, each of whom may belong to a distinct group with distinct consumption habits. As a result, coordinating consumer participation in demand response programs can give numerous benefits to the entire system. (Mohammadi et al. 2018)

To summarise, the macro energy hub paradigm improves system resilience while also providing economic and environmental benefits. However, because macro energy hubs have a huge number of data connections that to be processed, smart grid technology can help them work better.

The smart system concept is a generalised version of the smart grid that can manage several energy carriers to satisfy various demands. Smart systems have several advantages, including higher productivity and dependability, lower carbon emissions and energy use, better integration of renewable energy sources, real-time and integrated energy system control, and so on.

2.4 Smart Energy Hub and smart cities

Smart city concepts have gotten a lot of press in recent years because they use information and communication technology developments to improve the quality and efficiency of services and resources. Micrograds have the potential to be extremely useful in the construction of smart cities. (Shahzad et al. 2018)

The goal of the Smart City concept is to make better use of public resources by improving the quality of services provided to people while lowering government operating costs. (Alexandra et al. 2015)

The Energy Hub is a powerful idea of collecting, transforming, and distributing energy resources in the smart city. Power systems are becoming smarter and more automated, and this is referred to as smart grid. In addition to typical network responsibilities such as electricity production, transmission, and distribution, smart grids can store data, communicate, and make choices (Mohammadi et al. 2017).

Smart grids use advanced applications and communication, digital information, and automated monitoring technologies to construct, optimise, and improve the operation of energy network infrastructures. Smart grids result in increased demand-supply efficiency and effective use of existing infrastructure, reducing the need for system development. Smart grid, on the other hand, makes it easier to integrate renewable energy sources on the demand side, particularly in the form of distributed generation. (Maria and Michael 2016).

Increasing resource efficiency at the city level would allow for more environmentally friendly solutions and aid in the transition to a low-carbon economy while also addressing the issues of growing populations in such regions. Several UN, EU, and US projects have recently been launched to develop solutions for such sustainable cities. Among these are the United Nations' GI-REC (Global Initiative for Resource Efficient Cities), the European Union's European Innovation Partnership on Smart Cities and Communities (EIP-SCC), and the United States Smart Cities Initiative. (Edward et al. 2019). However, electricity networks are increasingly shifting toward intelligent systems and automated tasks, prompting the smart grid idea. Unfortunately, despite the extensive use of the term "smart grid" in the literature, no definitive and comprehensive definition of the term exists.

The smart grid is a modern power system that uses autonomous control of information and communication technologies and energy management infrastructures to improve efficiency and reliability. (D. Kolokotsa 2015). The smart grid is on the lookout for a compilation of these technologies to create a self-healing and more dependable network. Smart grid improves supply efficiency by maximising the utilisation of existing infrastructure, reducing the need for system expansion, and allowing the incorporation of renewable energy sources (D. Kolokotsa 2015).

On the consumer side, this means maximising the use of existing infrastructure, reducing the need for system expansion, and making it easier to integrate Renewable energy systems, particularly in the form of Distributed generations.

The use of smart meters and communication technologies is the first to build a smart grid, along with two-way communication and information technologies. These technologies will provide tools to predict different parameters and appropriate management procedures .data collected by these technologies can predict temperature, humidity and solar radiation and allow for two way communication. The two-way communication procedure can provide real-time data and a real-time monitoring system that can correct faults and make real-time adjustments for maximum energy consumption optimization (Konark and Lalit 2015).

2.5 Dashboard of Smart Energy Hub

To create long-term smart energy cities, it is necessary to encourage the development of platforms that give citizens benefits such as convenience, safety, and cost savings.

A smart city uses several sorts of sensors to capture electronic data and provide information that is then used to manage assets and resources efficiently.

Data about citizens, devices, and assets is processed and analysed to enable traffic and transportation systems, power plants, water supply networks, waste management, law enforcement agencies, information systems, schools, libraries, hospitals, and other community services to be monitored and managed (Sanguk et al. 2019).

The efficient management and exchange of energy will be used in the future buildings of sustainable smart energy city through the links between smart energy data analytics, energy prosumer, energy security, and renewable energy.

We are establishing a sustainable smart energy city idea, a platform-driven concept that provides convenience, safety, and cost savings to its residents by merging tailored services and companies into varied environments inside the current urban energy infrastructure.

Smart energy, smart meters, smart homes, buildings, factories, smart grids, and electric cars are all parts of a sustainable smart energy city. These aspects must be strategically linked to actualise the concept of a smart energy city fully. This would make the development of a Sustainable energy city more possible, quick, and cost-effective.

Following the organisation of the energy management strategy, the infrastructure required to operate it is established and designed around the IoT to enable the plan's implementation (Waleed et al., 2018). Smart cities are transformed into Sustainable smart city energy by IoT-focused infrastructure. The key purpose is to evaluate energy data supplied by the IoT and conduct efficient energy management simulations (Sanguk et al 2019).

3 Research Methodology

Choosing Hub Grade 4 as a case study for Energy Hub supports the research argument with in-depth analysis. Both types of hubs are practised in hub grade 4; for micro hub the collection of data from different types of facilities, residential. Commercial and industrial, and these readings collected from electricity sub-meters analysed by energy specialist in hub grade 4, then visualise these data using develops software and combine in macro energy dashboard, the practice of energy hubs and energy management practices is very mature in the UAE .data collected through several visits to Energy Hub of Enova by Veolia meeting energy specialists and discuss data processing and how analytical report and how energy specialist visualise these data on Hub Grade 4 dashboard.

There are missed opportunities to optimise energy consumption due to the lack of success stories of executed case studies. Although there are great opportunities to save energy and optimise energy consumption in existing buildings, these opportunities were missed because of the reluctance of building owners to accept energy-saving plans.

4 Hub Grade 4- a case study of Smart Energy Hub

Many countries are currently merging bespoke services and enterprises inside their energy infrastructure and urban surroundings to establish sustainable smart energy cities worldwide. As a result of these modifications, creating a Smart Energy Hub might be accelerated, providing citizens with benefits such as convenience, safety, and cost savings.

A sustainable city is a city that uses several sorts of sensors to capture electronic data and provide information that is then used to manage assets and resources efficiently. Data about citizens, devices, and assets are processed and analysed to enable traffic and transportation systems, power plants, water supply networks, waste management, law enforcement agencies, information systems, schools, libraries, hospitals, and other community services to be monitored and managed. (Sanguk et al. 2019) Enova by Veolia in 2014 launched Hub grade 4, a new energy hub that monitors and optimises energy, water, and material flows in real-time. Real-time data has been processed in this hub to improve resource use by municipal, commercial, and industrial clients.

Enova by Veolia is a regional leader in integrated energy and multi-technical services, providing clients with a full range of services. It offers customers performance-based Energy & Facilities Management solutions to assist them in meeting their financial, operational, and environmental objectives.

Enova began as a joint venture between Majid Al Futtaim and Veolia in 2002. Majid Al Futtaim is the Middle East's, Africa's, and Asia's largest shopping mall, community, retail, and leisure pioneer. Veolia is one of the well-known world organisations that leads the businesses of preserving the environment; their business is to optimise water consumption, waste management and energy management to help the world become sustainable and green.

The Hub grade 4 dashboard provides real-time data collected from connected sensors and submeters in buildings and services, then the collected data will be compared with benchmark readings and provide analysed feedback to the operation team to do tune-up to running equipment

The studied data is then provided in a reporting dashboard system that displays the most significant and valuable information from digital systems for quick decision-making and performance indicators to operational teams on the ground. Also hub grade 4 provide the customer with online access to reports and information to raise awareness among end-users.

Hub grade 4 incorporate all collected data from EMS, Waste Management Platforms, Water Quality Monitoring and Control Systems, BMS, CMMS, Asset Management software, SCADA systems, Carbon Footprint calculator, Indoor Air Quality monitoring applications. Financial analysis and benchmarking are also included in these systems' capabilities (Antonio and Patrice 2017).

4.1 Micro Hub Grade 4 model

The dashboard shown in Fig 4 shows real-time data for one of the shopping centres collected by installed sensors and submeters for measuring energy consumption (electricity & water).

These data will be examined against the baseline by making the comparison between actual energy consumption readings and the baseline; this will provide a continuous monitoring mechanism, as in case energy consumption is more than the base line energy consumption, the red sign will appear giving alarm to the operator to check the asset performance and bring energy consumption to positive magnitude , below is the legend represent the alarms appeared in monitoring mechanism dash board to ensure proper monitoring of energy optimisation process :

Table 1 – Monitoring Mechanism Dashboard

Facility	Utility	<A	A<B	B<C	C<
Shop.Cent1	electricity	<3.85%	3.85%<7.7%	7.7%<10%	10%<
Shop.Cent1	Water	<2%	2%<7.28%	3%<4%	4%<
Shop.Cent2	electricity	<3.69%	3.69%<7.38%	7.38%<10%	10%<
Shop.Cent2	Water	<3%	3%<4%	4%<5%	5%<
Shop.Cent3	electricity	<3.17%	3.17%<6.34%	6.34% <10%	10%<
Shop.Cent3	Water	<5%	5%<6%	6%<7%	7%<

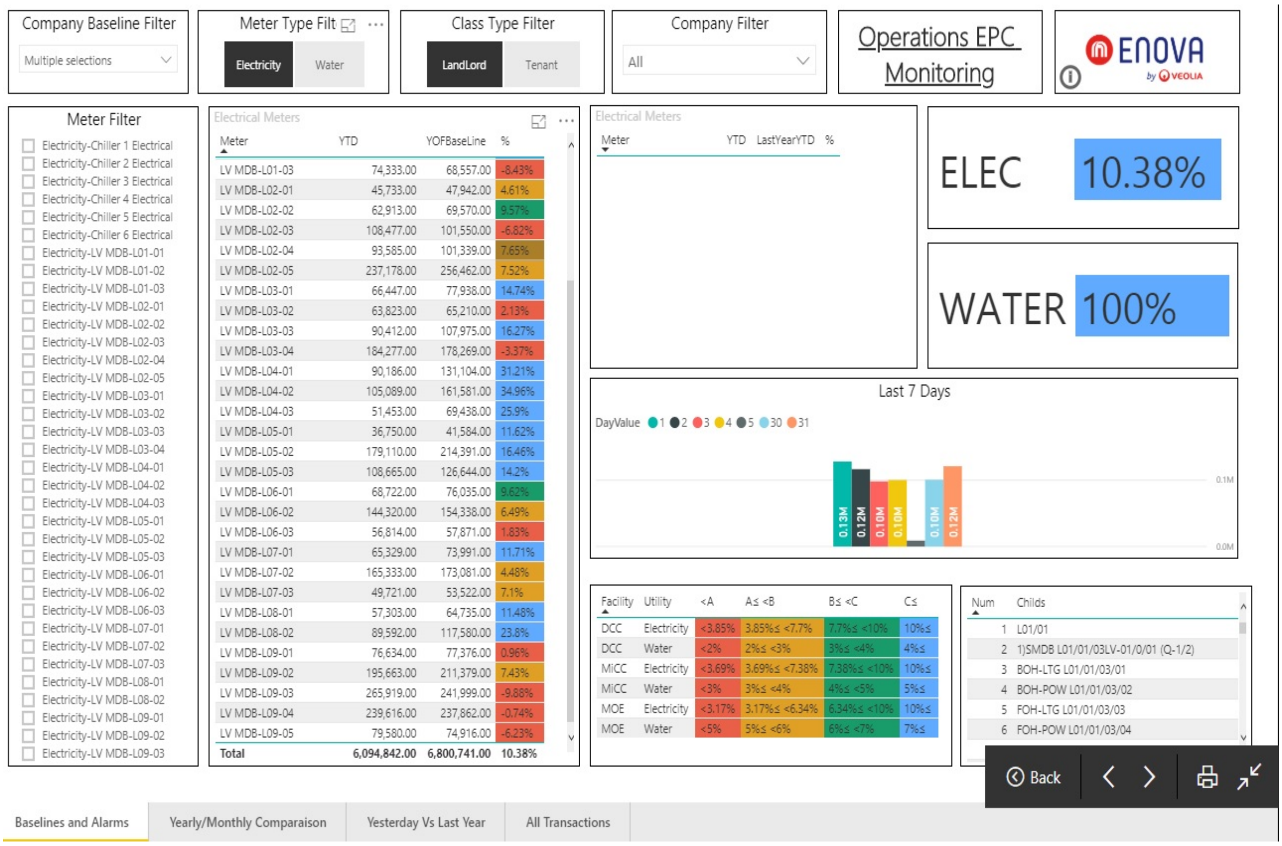
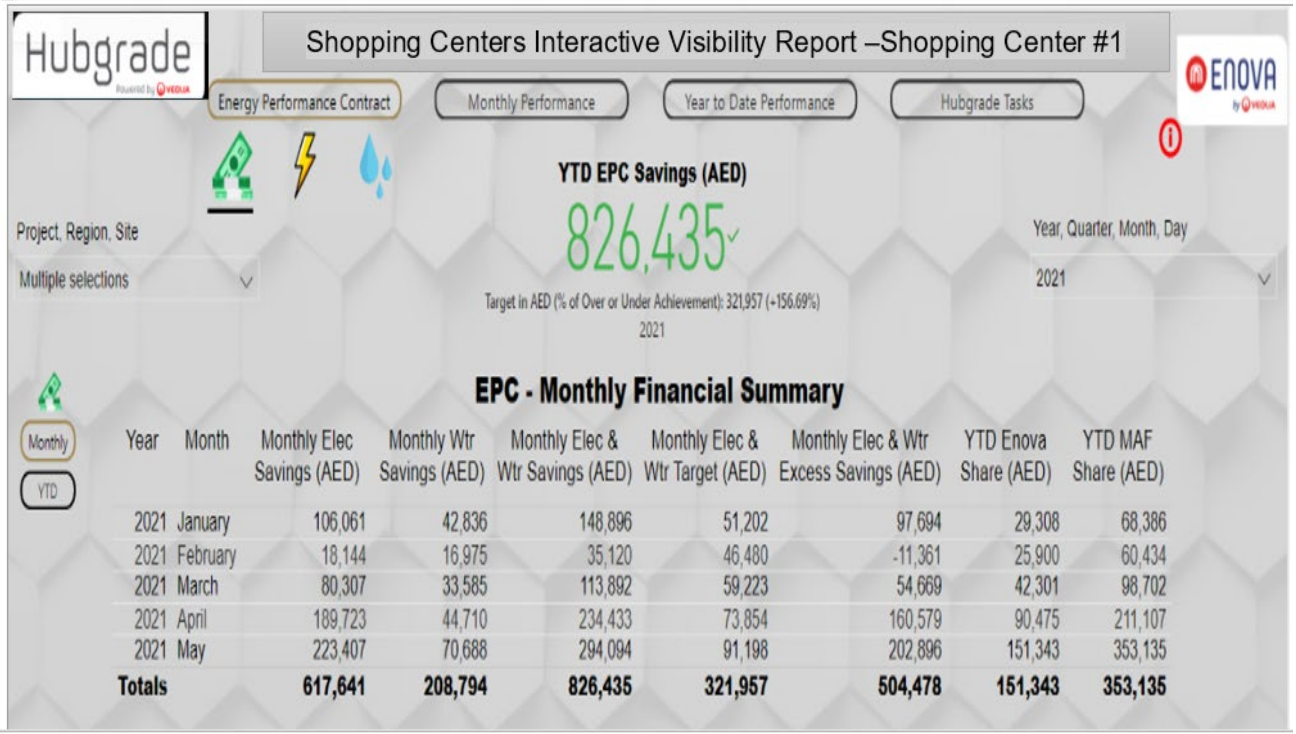


Fig 4 Dashboard showing metering system readings in one of the shopping centres

Then in Hub grade 4, the energy team will analyse collected data and summarised the results as shown in Fig 5 and then use developed software and IoT technology to show total saved electricity in terms of KW, the dashboard showing saving electricity of 1,436,375 KW, which is equivalent to 617,641 AED and saved water 18,251M3 equivalent to 208,794 AED.



Year	Month	Monthly Elec Savings (AED)	Monthly Wtr Savings (AED)	Monthly Elec & Wtr Savings (AED)	Monthly Elec & Wtr Target (AED)	Monthly Elec & Wtr Excess Savings (AED)	YTD Enova Share (AED)	YTD MAF Share (AED)
2021	January	106,061	42,836	148,896	51,202	97,694	29,308	68,386
2021	February	18,144	16,975	35,120	46,480	-11,361	25,900	60,434
2021	March	80,307	33,585	113,892	59,223	54,669	42,301	98,702
2021	April	189,723	44,710	234,433	73,854	160,579	90,475	211,107
2021	May	223,407	70,688	294,094	91,198	202,896	151,343	353,135
Totals		**617,641**	**208,794**	**826,435**	**321,957**	**504,478**	**151,343**	**353,135**

Fig 5: summary of energy consumption results for selected shopping centres

In Fig 6, we may consider the dashboard a micro energy hub dashboard representing energy optimisation for shopping centres at the micro-level where clients and service providers can monitor the progress of building system energy optimisation plans.

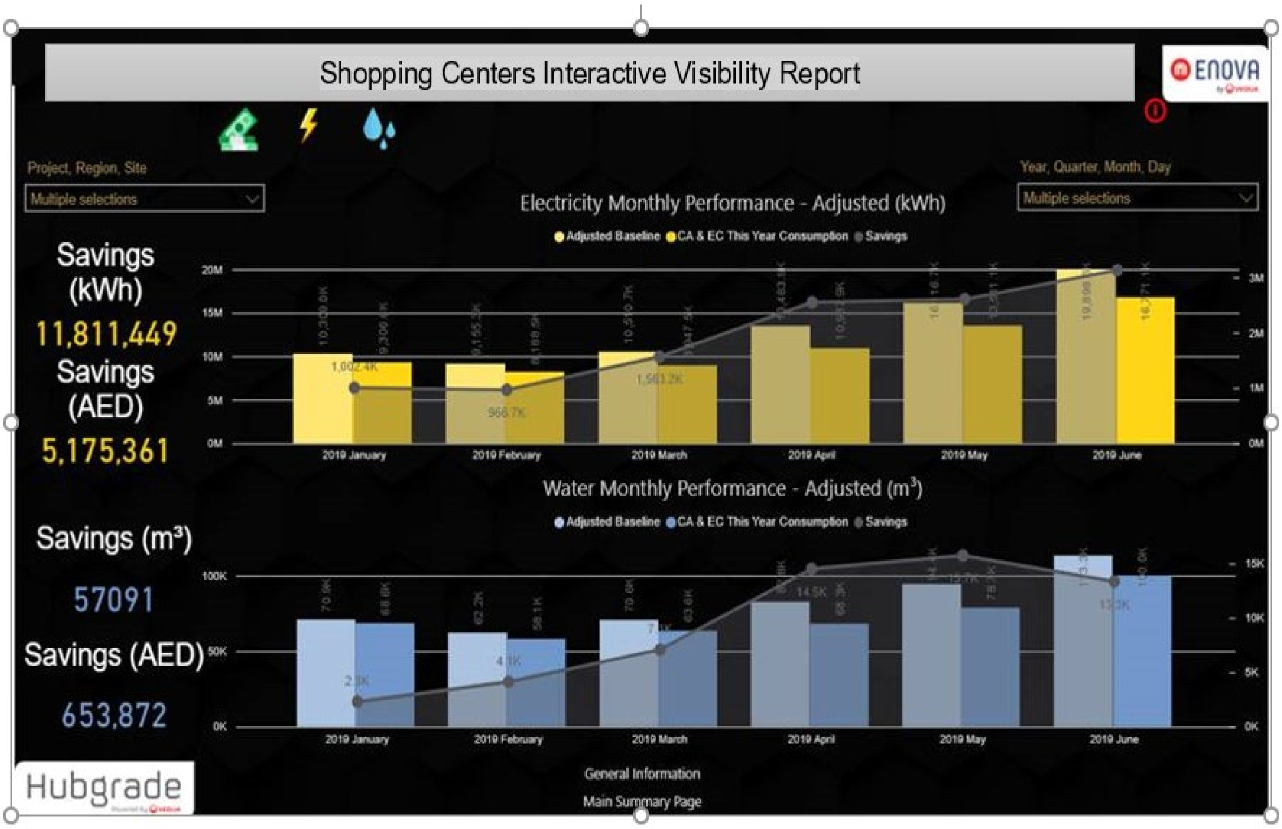
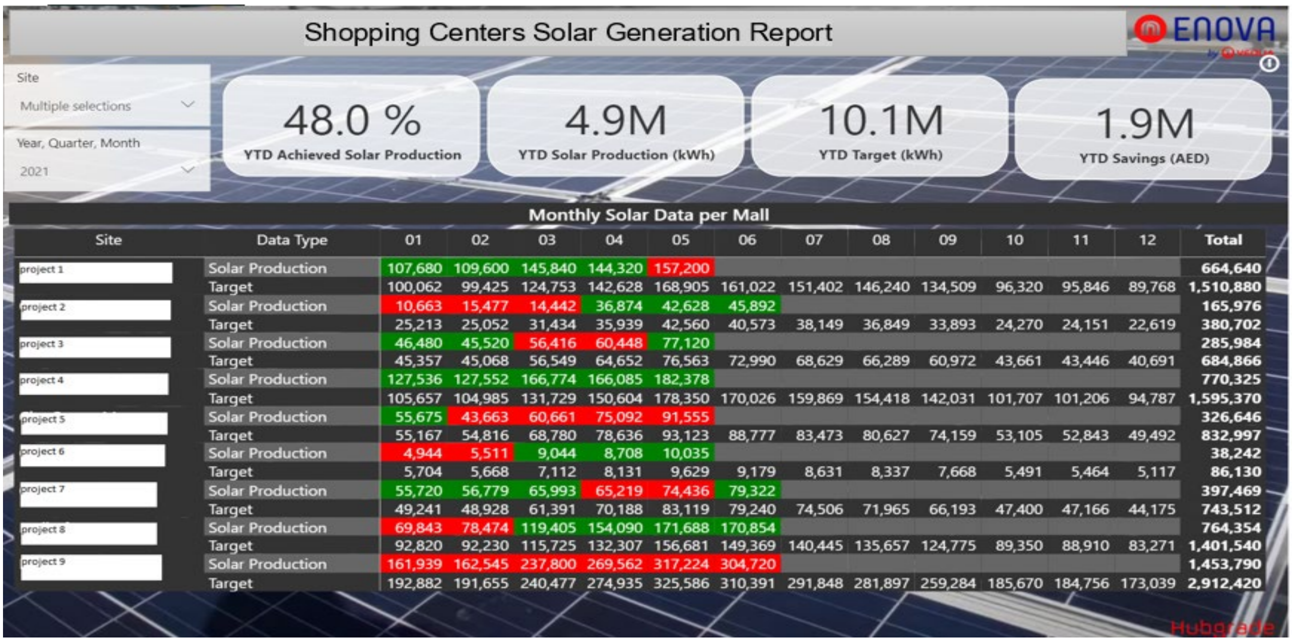


Fig 6 :Dash board for energy optimisation results for shopping centers as model for Micro energy Hub

4.2 Micro Hub Grade 4 model for renewable energy

The integration of renewable energy in hub grade 4, as shown in Fig 7, will help the implementation of microgrids and will develop the implementation of sustainable smart energy cities and support the increasing demand for power and reduce carbon footprint. The dashboard for a solar system for all shopping centres connected to solar system submeters sends energy generated readings in real time to Hub grade 4, compared with targeted values set by the energy team to monitor solar system performance. The solar dashboard reports 4.9Mil KW generated from solar grid installed in shopping centres from Jan 2021 till June 2021, achieving 48% from the yearly target.



Site	Data Type	01	02	03	04	05	06	07	08	09	10	11	12	Total
project 1	Solar Production	107,680	109,600	145,840	144,320	157,200								664,640
	Target	100,062	99,425	124,753	142,628	168,905	161,022	151,402	146,240	134,509	96,320	95,846	89,768	1,510,880
project 2	Solar Production	10,663	15,477	14,442	36,874	42,628	45,892							165,976
	Target	25,213	25,052	31,434	35,939	42,560	40,573	38,149	36,849	33,893	24,270	24,151	22,619	380,702
project 3	Solar Production	46,480	45,520	56,416	60,448	77,120								285,984
	Target	45,357	45,068	56,549	64,652	76,563	72,990	68,629	66,289	60,972	43,661	43,446	40,691	684,866
project 4	Solar Production	127,536	127,552	166,774	166,085	182,378								770,325
	Target	105,657	104,985	131,729	150,604	178,350	170,026	159,869	154,418	142,031	101,707	101,206	94,787	1,595,370
project 5	Solar Production	55,675	43,663	60,661	75,092	91,555								326,646
	Target	55,167	54,816	68,780	78,636	93,123	88,777	83,473	80,627	74,159	53,105	52,843	49,492	832,997
project 6	Solar Production	4,944	5,511	9,044	8,708	10,035								38,242
	Target	5,704	5,668	7,112	8,131	9,629	9,179	8,631	8,337	7,668	5,491	5,464	5,117	86,130
project 7	Solar Production	55,720	56,779	65,993	65,219	74,436	79,322							397,469
	Target	49,241	48,928	61,391	70,188	83,119	79,240	74,506	71,965	66,193	47,400	47,166	44,175	743,512
project 8	Solar Production	69,843	78,474	119,405	154,090	171,688	170,854							764,354
	Target	92,820	92,230	115,725	132,307	156,681	149,369	140,445	135,657	124,775	89,350	88,910	83,271	1,401,540
project 9	Solar Production	161,939	162,545	237,800	269,562	317,224	304,720							1,453,790
	Target	192,882	191,655	240,477	274,935	325,586	310,391	291,848	281,897	259,284	185,670	184,756	173,039	2,912,420

Fig 7: Solar energy generation Dashboard for shopping centers

4.1 Macro Hub Grade 4 model

The sustainability report shown in Fig 8 represents a summary report for all energy optimisation activities monitored by Hub grade 4; it acts as a Macro energy hub dashboard for all projects controlled by hub grade.

It represents the integration of several micro hubs like residential buildings, hotels, shopping centres..etc. under the control of Macro energy hub, which gives financial, economic and technical benefits and increases the contribution of preserving the environment protect the environment.

To summarise the results of energy optimisation in all projects as visualised in the sustainability report, hub grade 4 was able to save 254 million kW power and around 3million cubic meters of water and give a financial saving of about 138 million AED.

These results are encouraging results to motivate public and private sectors to adopt energy-saving and energy management to benefit from efficient usage of energy and push authorities to adopt solid policies to move the community to more efficient power consumption as Jaffi and stain argue that Each kilowatt of energy of plant capacity reduced to save the city more than the individual who decides to save energy (Jaffi and Stain 1994).

Applying the hub grade 4 concept on the city level that adopts efficient energy consumption and promotes a developed energy management system that can link different kinds of micro energy hubs using smart digital technologies will create a sustainable smart energy city.

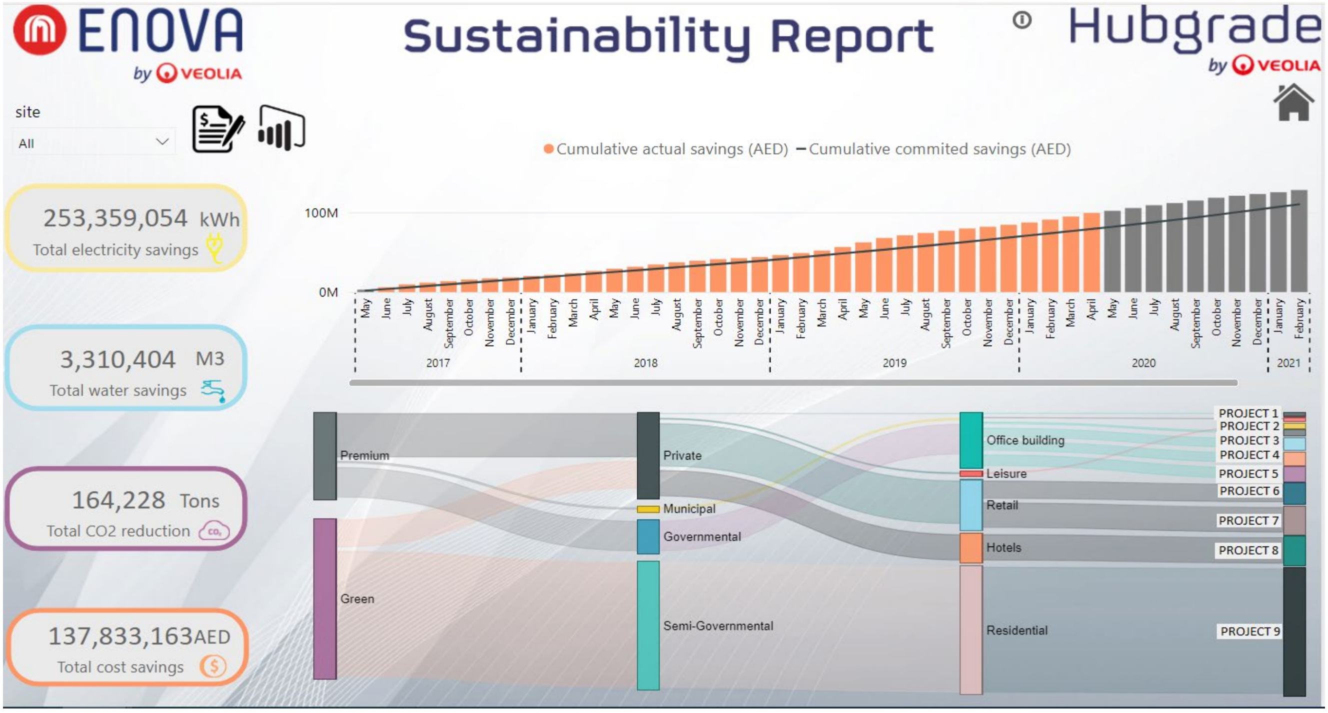


Fig 8:Comprehansive Macro Dashboard for a different types of buildings, residential, commercial and industrial

5 Findings and Discussion

The research and case study reveal that the impact of the increased population on earth require huge efforts to customise the consumption of natural resources; the optimal use of these resources requires a centralised monitoring system and integrated energy management.

Introducing Energy hub as a concept provides a powerful tool to manage energy flow and monitor energy consumption in real-time utilising new technologies and IoT, providing required data to the energy hub dashboard to visualise the results of optimising energy consumption and minimise carbon footprint.

Applying the concept of energy hub on city level introduces two types of energy hub. First, one micro hub and 2nd is macro hub depending on the type of facilities and consumer and consumption pattern; the micro-energy hub can be residential, or commercial or industrial, while macro hub can integrate several types of micro hubs, moving toward smart energy system with developed new technologies evolving energy management to be smarter and smarter towered machine learning and digital twin to reach to optimal use of energy resources.

Hub grade 4case study shows the benefits of employing energy hub on micro level and macro level leverage the huge amount of data and visualising the results on smart dashboards allowing operator and the client to take the right decision. It is a good model for creating a sustainable smart city that optimises its recourses.

6 Conclusions and Further Research

To create a sustainable smart energy city, it is essential to combine and customise several services and businesses within the structure of energy systems and city infrastructure.

A healthy society that uses smart technologies to manage a collection of smart city infrastructures that support sociotechnical and socioeconomic initiatives and celebrate cultural and ethnic diversity, for example, could play a key role in organising the global response to challenges posed by rapid urbanisation (Shahidehpour 2018).

Since an energy hub has the ability to integrate several services for different types of facilities, an energy hub is an excellent solution to optimise energy consumption as an integrated energy management system; the micro-energy hub can be a great solution to remodelling of energy consumption of residential, commercial and industrial facilities while Macro energy hub can integrate several micro hubs giving the advantages of technical, economic and environments benefits. However, due to the large volume of data and connectivity with a large number of sensors, the use of IoT and smart technologies became essential to explore the results of energy system optimisation moving these facilities to be smarter and smarter.

The case study shows considerable energy savings and proof that optimising energy consumption in micro and macro levels utilising smart technologies and IoT, presenting these results through the smart dashboard is the first step towards a sustainable smart energy city.

Below in Fig 9 is a model of a future sustainable smart energy city where centralised macro energy hubs adopt different services introducing new IoT and digital technologies will bring considerable energy savings besides minimising future plans for new power plants.

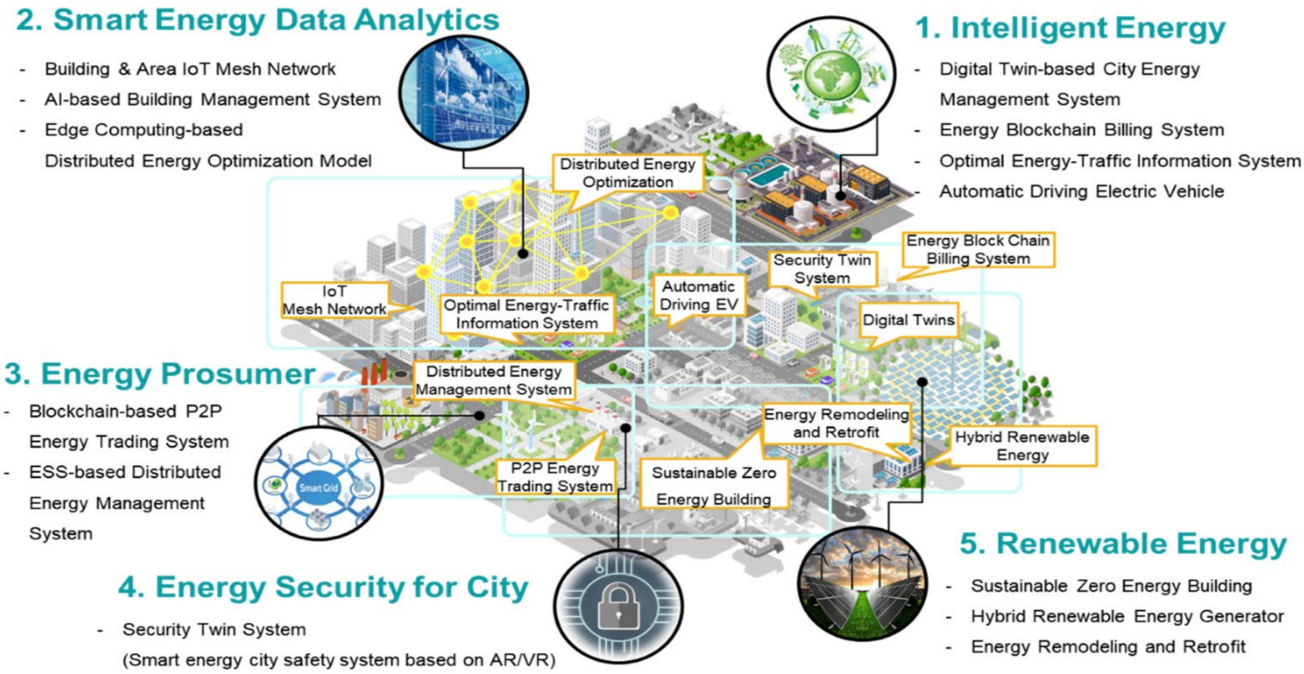


Fig 9: Future model for sustainable smart energy city (Sanguk et al. 2019)

Future plans require the intervene of governments to play a significant role to form new policies, new regulations to incentivise and promote sustainable smart energy cities and smart energy hubs to encourage communities and building owners, businesses to adopt building micro hubs as part of city infrastructure and connect these micro hubs to centralised macro hubs (Kablan, 2004).

Also, future studies should concentrate on the connectivity of all services using smart technologies creating digital twin model and building comprehensive smart energy hub controlled by city municipal as an urban twin model which deals with several services electricity, water supply, renewable energy, waste management, traffic, electric cars and city security system.

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Optimal Collaborative Energy Model among Vehicle-to-Home (V2H) and Solar Systems

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Abstract
Replacing traditional car engines with electric vehicles (EVs) has been suggested as an effective strategy to address climate change. The EV boom will also increase electricity demand especially if EV charging times coincide with peak-electricity demand. Most EV drivers are charging their vehicles at home, and some are doing it using solar-generated power. At the same time, the number of smart homes that can potentially coordinate the generation, consumption, and storage of energy across the available resources is steadily increasing. Because EVs spend more than 90 percent of their use time off the road and parked, their batteries could be used to store and distribute solar-generated electricity. With the aid of vehicle-to-home (V2H) systems, we can communicate with the smart home to store and discharge electricity generated from renewable energy sources. The use of EVs as electricity storage needs to be properly managed to not only avoid the negative impacts of EV charging on the power distribution network but also to help strengthen the grid and reduce operating costs. Among available renewable energy systems, rooftop solar represents a significant source of power generation in smart homes. This study investigates energy models to optimize energy flow among smart homes equipped with rooftop solar and EVs.

Keywords
Vehicle-to-Home, Solar Systems, Electric Vehicle, Smart Buildings

1 Introduction

Saving energy is neither simple nor easy. It requires innovation, planning and last but not least, changing deep-rooted behavior. Most world energy supplies come from high-carbon sources such as fossil fuels that cause climate change. Only 11.4% of global primary energy came from renewable energy sources such as hydropower, wind, solar, bioenergy, geothermal, and wave and tidal in 2014 (Schlömer *et al*. 2014). Renewable energy sources share in the world energy production raised to about 26% in 2018 (IEA 2020a) and continues to increase.

One effective and feasible strategy to counter global climate change is replacing traditional cars with electric vehicles (EVs). The boom in EVs has its challenges as it increases electricity demand and makes the case less environmental-friendly when the EV charging times coincide with peak-electricity demand and or when the electricity is provided by fossil-fueled power plants. It is important to note that many drivers are charging their EVs at night or using solar-generated power to reduce demand from the grid at peak hours. In addition, the number of smart homes that can potentially coordinate the generation, consumption, and storage of energy across the available resources is steadily increasing. As all vehicles are parked 95% of the time, the batteries in electric vehicles could be used to dispatch electricity to the grid (Yura 2020).

Returning electricity to the grid is called vehicle-to-grid (V2G) which was introduced by Kempton and Letendre (1997). The EV batteries could be used to store and distribute solar-generated electricity. With the aid of vehicle-to-home (V2H) systems, EVs can communicate with the smart homes to store and discharge electricity generated from renewable energy sources. Penetrating renewable energy sources into power systems will require energy storage systems to smoothly support electric grids so that the electrical power demand and provided power are met at all times (Mwasilu *et al.* 2014). Therefore, EVs are suitable to be used as dynamic energy storage systems in both V2G and V2H systems. As a result, the network of EVs can perform as the virtual power plant (VPP) concept model (Vasirani *et al.* 2013).

The connection of EVs to the power grid can increase the short-circuit currents, bring the voltage level out of standard limits, increase the power demand, and impact the lifespan of the pieces of equipment (Dulău and Bică 2020). The use of EVs as electricity storage needs to be properly managed to not only avoid the negative impacts of EVs charging load on the power distribution network but also to help strengthen the grid and reduce operating costs. At the time of this study, Nissan (Leaf & e-NV200), Mitsubishi (Outlander) and Renault (Zoe) are the only EVS that support bidirectional Charging technology.

The scope of this study does not include the economic viability of V2H and the battery degradation. Economists and researchers have debated these issues for years, and consensus does not appear likely mainly because there are multiple factors impact the degradation of the battery (e.g. state of charge (SoC) of the battery and depth of discharge (DoD), how often and how much you discharge (discharging current), at what temperature, etc). This study seeks to explore the optimal collaborative energy model among V2H and solar systems. The next section discusses the background to the study, thereby highlighting its importance. This is followed by a discussion of an optimal energy model and a case study. A presentation of the key findings from the study and their wider implications, and trajectories conclude the paper.

2 Vehicle to Home (V2H)

V2H is a concept that enables EV batteries to associate with homes. Any vehicle that can be connected to an electric plug can be used for V2H technology (Morris & Cleveland 2006). The purpose of the V2H is to optimize transportation and usage of EVs as electrical energy distribution and using them as VPPs. V2H helps keep renewable energy in the energy system and it causes moderation in climate change (Musio *et al.* 2010). In this concept, electric car batteries would store electrical energy from the power distribution system and dispatch it back based on the electricity demand. All these batteries would join a network and be used for 'peak shaving' (sending power back to the grid at high demand) and 'valley filling' (charging when demand is at its lowest point which is at night) to balance the distributed load (Wagner 2014). In many power generation systems, gas or combined power plants are used as peaking units. These systems are fast to run but not climate-friendly (Nag 2014). However, renewable energy sources are not as fast to run depends on the time of the day and environmental situations. This is why excessive renewable energy goes to waste due to being more than power demand at night if it is not stored or used (Nag 2014). This is where V2H functions to save more renewable energy. The batteries are being charged by electricity produced by renewable sources at night when the demand is at its lowest point. Then, a few hours later, when load demand tends to reach its peak load, the power stored in batteries can be released to take some percentage of the load from the grid and stabilize renewable energy in the system. This will cause the load curve to level and also is much cheaper than building new utilities (Lund & Kempton 2008). "Carbitrage" is a combination of the words "Car" and "Arbitrage". Arbitrage is benefiting from simultaneously purchasing and selling the same asset in different markets with different prices to profit from this difference. The carbitrage presents the economic benefit of the V2H concept (Kim et al. 2012).

It is anticipated that there will be 116 million EVs by 2030 which indicates many new demands on electric utilities (Statista 2021a). An average residential house consumes less than 24 kWh in a day (EIA 2020). Average electric car batteries have capacities of 45 kWh (Statista 2021b). Therefore, they can supply more than enough electricity for an average residential building. This is another reason for coining the portmanteau carbitrage; the battery can be charged at night at the base load curve and support the home at the peak to form an electricity cost reduction by reducing the energy demand at peaking periods (Naghibi 2018).

Household building and transportation energy consumption play an important role in global energy consumption with 24% of energy usage which is 6.4 PWh of energy (IEA 2020b). Therefore, considering enhancing energy efficiency in the building and transportation sectors is a great potential for saving energy and provide a healthier living environment for people around the globe.

3 Optimal Energy Model

We limit the scope of the study by focusing on small-scale cases where a household member or members live in a house suitable for solar power. We use a case study with real energy data in the next section to further demonstrate the application of the proposed model. The objective is to determine the optimal use of solar energy (production, storage, and distribution) to achieve maximum profit per unit of inputs used (e.g. \$/kWh). Figure 1 shows the architecture of the model beginning at t_i, i=1 with the time interval of t_{i+1}- t_i.

The U.S. Department of Energy compared energy costs per mile for electrical and gasoline-fuelled vehicles and concluded that the energy cost of EVs with electricity cost of about 30 cents per kWh is equal to that of gasoline vehicles with gasoline cost per gallon of \$3.50 (DOE 2019). Since the average cost of solar energy per kWh is between 6-12 cents, charging EVs using a solar system is undoubtedly the optimum solution. As shown in Figure 1, the energy model recommends charging the EV when this option is available.

When solar is used as the primary energy source, the expected supply, S_{solar}, can be calculated as follows:

$$S_{solar} = E_{cell} \times G \times A_{cell} \times (1 + (TkP \times (AT - 25)) \quad (1)$$

where S_{solar} is measured in watts, E_{cell} is the solar cell efficiency (%) under standard test conditions (temperature of 25ºC, irradiance of 1000 W/m^2, air mass 1.5 spectrum), G is the irradiance of input light (measured in W/m^2), A_{cell} is the surface area of the solar panels (measured in m^2), TkP is the temperature coefficient of the solar panel (%/ºC), and AT is the ambient temperature (ºC).

The charging time, t_C depends on the state of charge (SoC) of battery (%), vehicle acceptance rate (VAR), and the charging station delivery rate (DR) (both in kW). For example, if the VAR of an EV is 4 kW and the station's maximum output capacity is 5 kW, then it takes 5 hours to fully charge an empty 20 kWh battery. The following equation is used to calculate the charging time:

$$t_C = (1 - SoC) \times C / \min(VAR, DR) \quad (2)$$

where C is the battery capacity (kWh) and t_C is the charging time (hr).

If charging the EV is not possible (whether the EV is not at the charging station or it is fully charged), the solar power should be used to power the house. When the solar system is producing more than the house need ($S_{solar} > D_{home}$), any excess electricity (i.e. S_{solar} - D_{home}) is fed into the electric utility's grid. S_{home} is the electricity consumption for the house.

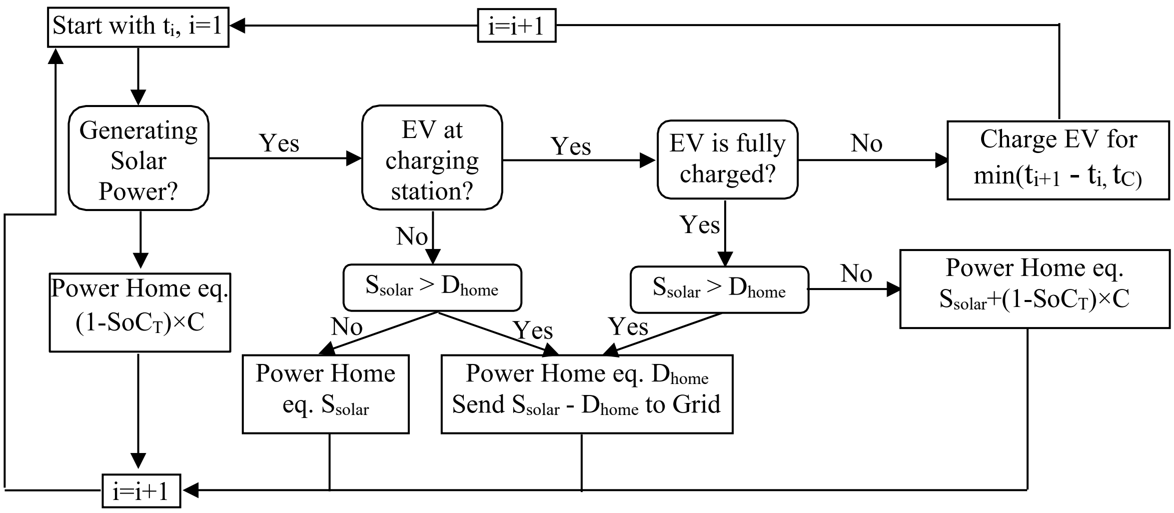


Figure 1. V2H with solar system energy model architecture

In this study, the energy model is developed based on a standard electricity plan, in which the same rate is paid for electricity regardless of the time of day. The EV can supply homes with power generated from its battery when the solar system does not produce sufficient electricity to power the house. It is important to determine the threshold SoC (or SoC_T) below which the EV stops discharging the stored electricity. A fully charged EV with 100 kWh battery capacity and SoC_T of 20% can discharge up to 80 kWh. The threshold SoC can be calculated using the following equation:

$$SoC_T = 1 - \frac{P(S_{solar} \rightarrow EV)}{P(\sum_{j=1}^{N} D_{trans.})} \quad (3)$$

Where $P(S_{solar} \rightarrow EV)$ is the probability that the EV is charged with solar power and is calculated using equation 4, and $D_{Trans.}$ is the probability of EV electricity consumption during a given period of time (from j =1 to N). For instance, we can calculate the EV electricity consumption per day for a 7-day (one week) period. In this case, j represents a daily time interval and N=7. Since the SoC_T is about the likelihood of certain events occurring in the future, we are using probabilities to quantify the energy supply and demand to deal with uncertainty.

$$P(S_{solar} \rightarrow EV) = \sum_{i=} \begin{cases} 0 & if\ EV\ is\ not\ at\ the\ charging\ station \\ S_{solar} \times i & if\ EV\ is\ at\ the\ charging\ station \end{cases} \quad (4)$$

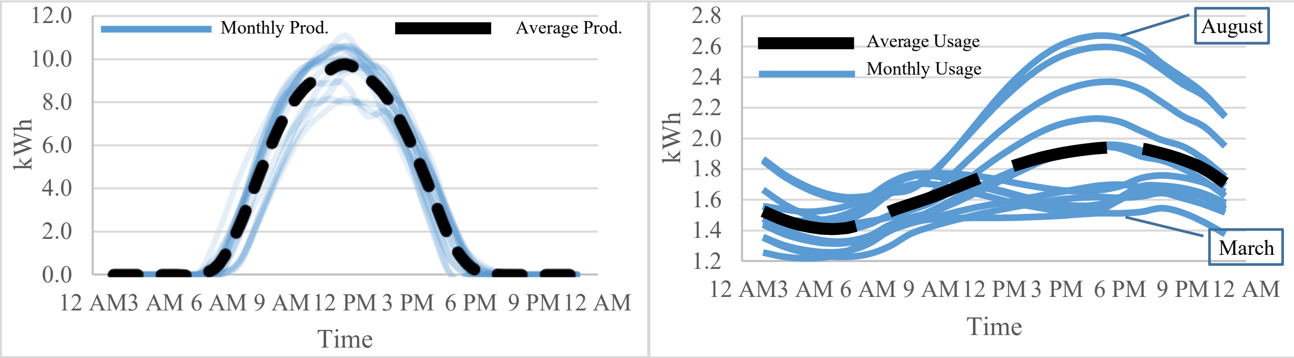
In order to calculate the SoC_T, we also need to decide about the associated confidence level. With a 95 percent confidence level, we would expect the SoC_T to be a given percentage 95% of the time.

4 Case Study

The described energy model is employed for finding the optimal solution for managing the energy supply and demand of a single-family house in Houston, Texas. Since the average size of homes in the US is around 226 m^2 (2430 SF), a 223 m^2 house (2400 SF) is selected for the case study. Figure 2 shows a conceptual model of the house with the available rooftop area of 200 m^2 (around 2150 SF) for installing solar panels (around 70% of the roof area).

Figure 2. Architectural model of the case study project (an average size house in the US)

We use equation 1 to estimate solar power production for the case study. The hourly temperature and irradiance of the house location along with an efficiency of 15% and temperature coefficient of -0.44%/ ^oC for a typical solar panel is used for the calculation. Figure 3-a shows the S_{solar} for the case study. It is expected that the solar system will generate 875 kWh per month (daily average ≈ 72 kWh). For estimating the D_{home}, we use the average hourly electricity use for a Texan household in 2020. The data is adopted from the US Energy Information Administration (EIA) and shown in Figure 3-b (daily average ≈ 40 kWh).



(a) (b)

Figure 3. (a) Hourly electricity production (S_{solar}) for the case study (b) Hourly electricity consumption (D_{home}) in a Texan home

The average commute distance and time of travel for a Texan is used to calculate the transportation energy consumption ($D_{trans.}$). The average weekday commute distance and time for someone living in the project area is 45.5 miles and 32.7 minutes (or 91 miles and 65.4 minutes per day if we assume a round trip), respectively. The weekend commutes are 25.8% of the weekdays. The information is based on data collected in the American Community Survey (ACS) conducted annually by the U.S. Census Bureau. We used the traffic data for interstate highways to estimate the travel time. Figure 4 shows the travel time distribution per weekdays and weekends.

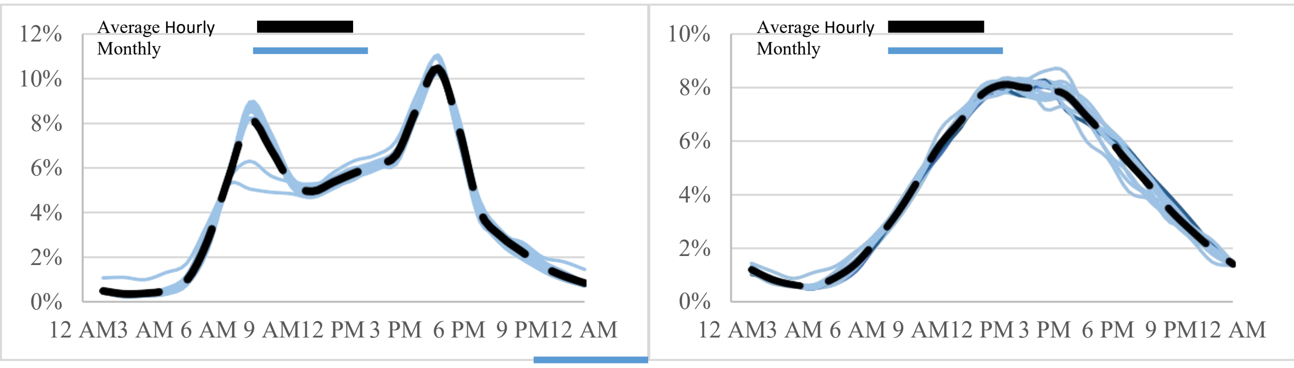


Figure 4. Hourly traffic time (a) weekdays (b) weekends

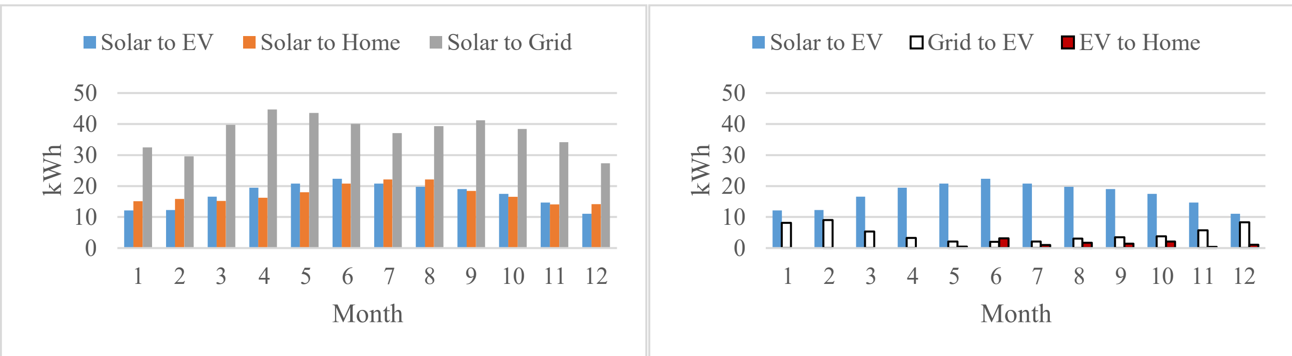
We collected energy consumption data for thirteen EVs available in the market. On average, EVs can travel 100 miles by using an average of 29.85 kWh energy (or around 48 kWh/100 km). The average estimated battery capacity is 43 kWh and 4 kWh/hr charging time rate is used in the study. The proposed model is used to show the optimal scenario for producing, storing, and distributing energy. We begin the analysis at t = January 1st, 12:00 am with a fully charged EV. We also assume that January 1st is Monday, a working day.

Table 1 shows the results of the energy production and distribution for the case study project. Please note that the amount of electricity stored in the EV and returns to the home is calculated based on SoC_T of 60%. This amount varies depending on the solar power generation, energy consumption, and the number of holidays and weekends per month. For example, when the solar power is less than 2,000 kWh per month, there is not much opportunity for the EV to return the power back to the home. December is an exception because of the reduced number of working days in this month. Our analysis shows that only weekends or holidays allow for powering home with the electricity stored in the EV's battery. Also, the SoC_T plays a major role in the amount of EV to Home power. The SoC_T is found to be 100% for a 7-day (one week) period. That means if we want to have enough electricity to commute for a week, there may not be any electricity that returns to the home. The model is analyzed for a 2-day period with an approximate SoC_T of 60% (refer to equations 3 and 4).

Table 1. The Results of the Energy Analysis for the Case Study

Month	No. of Days	No. of Weekdays	S_{solar} (kWh)	Solar to EV (kWh)	Solar to Home (kWh)	Solar to Grid (kWh)	Grid to EV (kWh)	EV to Home (kWh)
1	31	22	1,851	375	468	1,008	252	0
2	28	20	1,614	342	445	828	252	0
3	31	23	2,217	514	472	1,230	164	0
4	30	22	2,409	583	486	1,340	96	0
5	31	22	2,553	643	559	1,351	64	12
6	30	22	2,494	669	622	1,202	60	93
7	31	23	2,478	644	686	1,148	64	29
8	31	23	2,518	614	686	1,218	92	52
9	30	21	2,360	572	553	1,235	104	40
10	31	20	2,247	542	514	1,191	116	64
11	30	20	1,887	440	422	1,025	172	11
12	31	17	1,630	345	440	845	256	34

To better understand the energy production and distribution per month, the amounts listed in Table 1 are normalized based on the energy per day and shown in Figure 5. Although the proposed energy model gives the highest priority to the Solar to EV option, the availability of the EV at the charging station requires the EV to rely on the grid particularly during weekdays and after 6-7 pm when there is no sunlight. Another contributing factor is the transportation energy consumption ($D_{trans.}$) for the case study. To commute around 91 miles per day, a commercially available EV with an average efficiency of 29.85 kWh per 100 miles needs around 27 kWh per day. Not only this amount account for around 40% of the total solar power, but also the solar system barely produces this amount when the EV is available at the charging station (in the morning or evening).

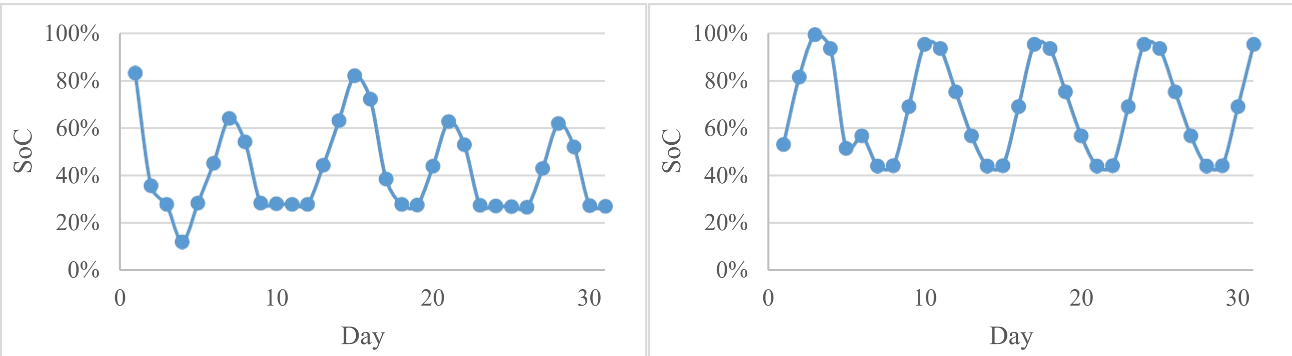


(a) (b)

Figure 5. Energy communications between the Home, Grid, and the (a) solar system (b) EV

Because the EV is not at the charging station during the peak solar energy production, and the home demand D_{home} is lower than the S_{solar} during these times, most of the energy produced by the solar system will be sent to the grid (see Figure 5-a). When the solar system produces less energy during November through February, the EV relies more on the grid to meet its energy need. On average, the EV has to use the grid power 16 days a month from November through February. In contrast, only 10 days in a month the grid power is needed to meet the D_{trans}. during May through August. The EV does not communicate with the home during the first four months of the year (as shown in Figure 5-b). The electricity consumption in the house and the available solar power are two contributing factors. On one side, these months are typically characterized by relatively mild temperatures in the case study location and thus the energy demand for air conditioning is significantly reduced. On the other side, the solar system does not produce sufficient energy to meet the D_{trans}. and the D_{home}.

The energy production during the summer outweighs the rise in cooling demand. Therefore, the EV needs less energy from the grid and can return more energy to the home. Figure 6 shows the SoC of the battery in two different months to see the impact of the weather (temperature and sunlight) on the energy system. Please note that the average SoC per day is shown in Figure 6. The average SoC in January for the weekdays is 33% and for the weekends is 62%. The average SoC in July for the weekdays is 58% and for the weekends is 95%. Although the D_{trans}. remains the same in both January and July, but the 34% more solar energy production during July supplies enough energy for the EV to keep the SoC above 50% even during weekdays.



(a) (b)

Figure 6. SoC for the case study EV during (a) January (b) July

5 Conclusions and Further Research

The large-scale use of EVs has been recognized as a practical solution for reducing greenhouse gas emissions and mitigating the threat of global climate change. However, the rapid growth of EV use and their electricity demand can negatively impact the power distribution network since the majority of EVs are being charged at home. In this study, we explore the optimal collaborative energy model among smart homes equipped with rooftop solar and EVs. We apply the model to a single-family house in Houston, Texas as our case study and determine the optimal use of solar energy (production, storage, and distribution) to maximize profit. Our analysis shows that the amount of electricity stored in the EV depends on factors including solar power generation, energy consumption, and the number of holidays, and weekends per month and that only weekends and holidays allow for powering home with the electricity stored in the EV's battery. Future studies can test the robustness of the proposed energy model by performing a sensitivity analysis on the key parameters. They also can apply the proposed energy model to other case studies and also can consider other factors in their analysis.

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Net-Positive Water Systems for Schools in Drought-Stricken Areas

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Abstract
In many areas of the world, climate change is leading to higher temperatures and water scarcity. At the same time, rapid urbanisation is increasing the demand for existing water resources. As a result in many drought-stricken areas, water costs have rapidly increased and supplies are becoming more unreliable. Schools in drought-stricken areas are particularly vulnerable. Limited resources mean that schools struggle to pay additional costs for water. Health risks also mean that schools have to close when there is no water. Closing schools significantly affects the quality of education as teaching is disrupted and learning time is lost. It is, therefore, important to find alternative affordable and reliable water solutions for schools in drought-stricken areas. Rainwater harvesting offers a potential solution but there is limited research and guidance on how these systems work at schools. This paper addresses this gap by investigating whether a rainwater harvesting system can be developed that would enable schools to become more resilient to water scarcity and outages. Modelling carried out indicates that a rainwater harvesting system has the potential of generating sufficient water to exceed the water needs of the school and therefore enables it to be water net-positive. The study shows that the business case for rainwater harvesting appears weak where there is a reliable local municipal water supply. However, this changes when schools are faced with punitive drought tariffs and increasing water outages which force closures.

Keywords
Schools, rainwater harvesting, net-positive water systems

1 Introduction

Climate change is leading to the increased occurrence of droughts and water scarcity in South Africa. Rapid urbanisation has meant that there is increasing pressure on existing systems and municipal water supplies are becoming increasingly unreliable. This can have a devasting effect on schools that have to close as they require water for drinking, cleaning and flushing toilets. Unplanned school closures disrupt teaching schedules and valuable learning time is lost, negatively affecting the quality of education. To avoid deteriorating education outcomes it is important to identify alternative reliable and affordable water supplies. One option is a rainwater harvesting system that captures rainwater from roofs and hard surfaces when it rains and stores this. Water captured in this way is then available for drinking, cleaning and flushing toilets. While the approach appears promising, limited research on school rainwater harvesting systems has been carried out (Sturm, *et al.,* 2009).

This paper addresses this gap by presenting a case study of a school in a drought-stricken area of South Africa. Analysis of the school is carried out and rainwater harvesting systems are modelled to investigate potential impacts and applicability of the approach. The study aims to address the following questions:

- What are the patterns of water use in the school?
- Can a rainwater harvesting water system meet the water needs of the school?
- How financially feasible is a rainwater harvesting system at the school?

2 Water, Climate Change, Schools and Rainwater Harvesting Systems

Water use is increasing at twice the rate of population growth, and it is estimated that 450 million people in 29 countries suffer from water shortages (UNEP, 2008; UN-Water, 2019). In South Africa, rapid urban growth is increasing demands on existing water systems (South African Cities Network, 2014). Available capacity is rapidly being used and an increasing number of towns in South Africa have water requirements that exceed availability (Department of Water Affairs, 2013).

Climate change is exacerbating this situation (Muller, 2007; Department of Environmental Affairs, 2011). Higher temperatures are increasing demands on already stretched water systems and the more frequent droughts result in water shortages and outages (Englebrecht, 2017; UNEP, 2014). In many municipalities, ageing water delivery infrastructure has not always been maintained leading to significant losses of water through leakage (Wensley and Mackintosh, 2015; South African Cities Network, 2014; SAICE, 2011; Brikké and Vairavamoorthy, 2016). These factors have combined to result in increasingly unreliable water supplies in many areas.

Schools are particularly vulnerable to water shortages and unreliable supplies as they rely on water for drinking, cleaning and flushing toilets and outages can lead to school closure because of health concerns. Closing schools can have devastating knock-on effects as learning time is lost and exam results drop (Jasper, *et al.*, 2012).

Water shortages are also resulting in rapidly rising water costs as municipalities try to reduce water consumption by increasing tariffs. Schools with fixed government funding and limited fee income from parents find it difficult to absorb additional costs for water. It is therefore not only important to investigate ways of reducing the vulnerability of schools to water shortages, but also to make sure that solutions are affordable.

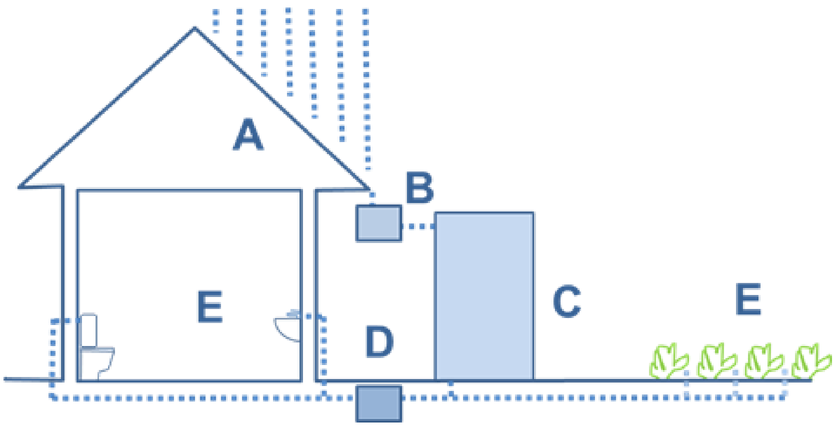

Figure 1. Elements of a rainwater harvesting system (author).

Rainwater harvesting systems capture rainwater for uses such as drinking, washing, irrigation and flushing toilets. Figure 1 shows the main elements of a rainwater harvesting system. Rainwater collection surfaces (A) harvest rainwater. Water is usually filtered near the collection surface (B) to remove debris and dust before being directed to a rainwater tank (C). Stored water may then be filtered (D) and used for drinking, cleaning and flushing toilets and irrigation (E).

Rainwater harvesting systems can be simple and consist of a small tank or can be complex and large and include pumps, header tanks, filtration and purification systems.

The methodology describes the analysis and modelling process that is used to design a simple rainwater harvesting system at a school. It shows how this can be evaluated in relation to water needs and financial viability.

3 Methodology

The methodology for the study aims to address the research questions identified in the introduction through analysis of a school in a drought-stricken area of South Africa. It consists of the following steps.

Firstly, data on the school is captured including photographs and plans. The population, schedule and water equipment in the school is also recorded to establish water requirements and water use patterns for the school over a year.

Secondly, an analysis is carried out to provide inputs for the design of the rainwater harvesting system. This includes an analysis of collection surfaces and the local climate. This establishes the volumes and patterns of water that can be captured by the rainwater harvesting system.

Thirdly, patterns of water consumption at the school are compared to patterns of rainwater harvested. This indicates whether harvested water meets requirements.

Finally, outline financial calculations are carried out to establish the cost of the rainwater harvesting system. Capital costs are compared to savings achieved through reduced, or avoided, use of water from the municipality to understand the business case for rainwater harvesting systems.

4 Case Study School

The case study school is near Loerie in the Eastern Cape, in South Africa. The area has experienced severe droughts and water rationing over the last 5 years. Figure 2 shows photographs of the school indicating the large roof areas available as collection surfaces.

Figure 2. Photographs of the Eastern Cape school.

Figure 3 shows a plan of the school with the main collection surfaces shown in dark grey (roofs). The roofs of the building are corrugated iron and can be used as the collection surfaces and have a runoff coefficient of 0.9. The collection surface area available for rainwater harvesting is 2,160 m^2 on a school site of 67,500m^2. The school has 202 learners and 8 full-time staff equivalents and therefore has 210 occupants on site.

Figure 3. A plan of the school indicating the site and the roof collection surface.

Figure 4 shows rainfall patterns for Loerie over a year. It shows that most rain falls in summer (November – March). It also shows that there is substantial rainfall in winter with a monthly rainfall of 60 to 70 mm for May, June, July, August and September.

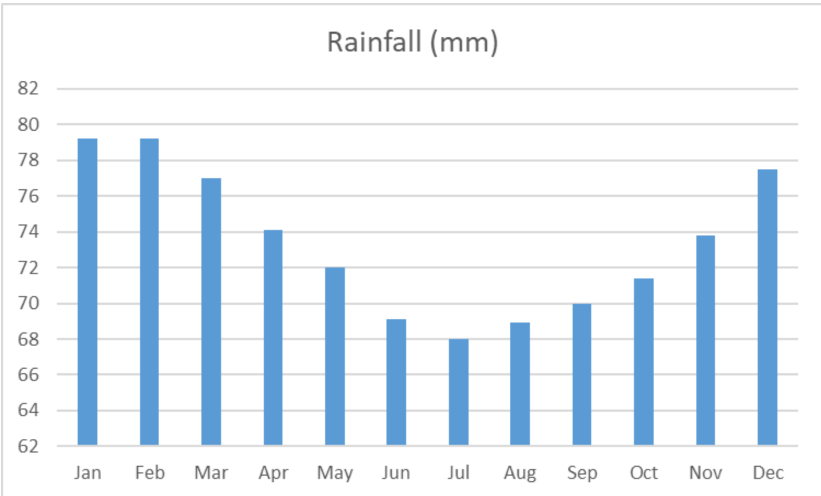

Figure 4. Monthly rainfall in Loerie, Eastern Cape.

Analysis of the site and rainfall can be used to design a rainwater harvesting system. Figure 5 shows that 1,695 kl of water can be harvested off the roofs of the school. Water required for the school to operate is calculated to be 15,975 litres per day and 134,300 litres per month based on the calculations in Figure 6.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Rainfall (mm)	79	79	77	74	72	69	68	69	70	71	74	78	880
Area	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	
Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Harvested (litres)	152 539	152 539	148 302	142 717	138 672	133 087	130 968	132 701	134 820	137 516	142 139	149 265	1 695 265
Consumption (litres)	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	134 300	1 611 600
Difference (litres)	18 239	18 239	14 002	8 417	4 372	-1 213	-3 332	-1 599	520	3 216	7 839	14 965	83 665

Figure 5. Rainfall harvested, water used at the school under conventional conditions and the difference (author).

Reference to Figure 5 shows that the rainwater collected will be almost sufficient to meet all the water needs of the school throughout the year. The exceptions are June, July and August when an additional 1,000 to 3,300 litres per month are required. These figures are reflected by the negative (-ive) values in the 'Difference' row.

The small additional amount of water required for June, July, and August could be addressed by improving the efficiency of the toilets, urinals and wash hand basin taps. Calculations for conventional fittings and use are indicated on the left in Figure 6 and those of efficient fittings and use are shown on the right.

Female Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	4	9	36
WC (half flush)	0	0	0
Wash handbasin	4	1	4
Water used per person per day (litres)			**40**

Female Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	6	6
WC (half flush)	3	4.5	13.5
Wash handbasin	4	0.5	2
Water used per person per day (litres)			**21.5**

Male Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	9	9
Urinals	3	0.5	1.5
Wash handbasin	4	1	4
Water used per person per day (litres)			**14.5**

Male Users	Uses/day	Consumption (litres)	Totals
WC (full flush)	1	6	6
Urinals	3	0.5	1.5
Wash handbasin	4	0.5	2
Water used per person per day (litres)			**9.5**

	Number	Consumption (litres)	Totals
Female Users	105	40	4 200
Male Users	105	14.5	1 523
Water used in the school per day (litres)			**5 723**

	Number	Consumption (litres)	Totals
Female Users	105	21.5	2 258
Male Users	105	9.5	998
Water used in the school per day (litres)			**3 255**

	Number	Consumption (litres)	Totals
Drinking water	210	2	420
Cleaning water	5	20	100
			520

	Number	Consumption (litres)	Totals
Drinking water	210	2	420
Cleaning water	5	20	100
			520

Water used in WCs, urinals and washhandbasins	5 723
Water used for drinking and cleaning	520
Daily water use in the school (litres)	6 715
Monthly water use in the school (litres)	134 300

Water used in WCs, urinals and washhandbasins	3 255
Water used for drinking and cleaning	520
Daily water use in the school (litres)	3 775
Monthly water use in the school (litres)	75 500

Figure 6. Water consumption in schools (conventional left, water-efficient right)(author).

Figure 7 shows that this intervention results in the rainwater harvesting volumes being substantially above requirements throughout the year. This is reflected in the large positive (+ive) values in the 'Difference" row. These positive values represent available water that could build a significant 'buffer' of stored water that would enable the school to be resilient to drier years when the rainfall was irregular and dropped below the average.

This arrangement would enable the building and water systems to be defined as net water positive. Net water positive buildings are defined in the following way:

'designed, constructed and operated to greatly reduce total water consumption, and then use harvested, recycled and reused water such that the amounts of water consumed is the same as the amounts of water that is produced (Net Zero), or if the water recycled/ produced is greater than the water consumed (Net Positive)' (GBCSA, 2017).

In this case, the volume of additional, net positive water could be substantial (790 kl) and can be shared with the local community if this is required because of water shortages or used to irrigate school gardens.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Totals
Rainfall (mm)	79	79	77	74	72	69	68	69	70	71	74	78	880
Area	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	2 140	
Factor	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
Harvested (litres)	152 539	152 539	148 302	142 717	138 672	133 087	130 968	132 701	134 820	137 516	142 139	149 265	1 695 265
Consumption (litres)	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	75 500	906 000
Difference (litres)	77 039	77 039	72 802	67 217	63 172	57 587	55 468	57 201	59 320	62 016	66 639	73 765	789 265

Figure 7. Rainfall harvested, water used at the school under efficient conditions and the difference (author).

The data from Figure 7 can also be used to propose the size of rainwater harvesting tanks. The drought and irregular conditions suggest that at least 3 months of water supply should be stored. This provides a figure of about 210kl of water.

In the existing school, a simple way of providing this volume would be through the installation of 21 free-standing plastic tanks of 10,000 litres located close to collection surfaces. These would be connected to downpipes off roofs and placed on concrete stands. They would then be connected to bathrooms, drinking taps and kitchens and a pressure pump used to supply water. As water will be used for drinking an additional allowance should be made for filtration. The approximate cost of this system in South Africa Rand (ZAR) is indicated in figure 8. At the time of writing the exchange rate between the South African Rand and the United States Dollar was about15 Rand to the Dollar.

Component	Cost	Number	Totals
Tanks	10 000	21	210 000
Bases	2 000	21	42 000
Collection plumbling	1 000	21	21 000
Distribution plumbing	1 000	21	21 000
Drinking water filtration	2 000	3	6 000
Capital Cost			**300 000**

Figure 8. Capital costs of a rainwater harvesting system at the school in South African Rands (R).

Component	Volume (kl)	Months	Tariff (R/kl)	Monthly fixed charge	Annual saving (R)
Rainwater harvesting	75.50	12.00	14.08	149.70	14,552.88

Figure 9. Annual savings generated by a rainwater harvesting system at the school.

Component	Capital Cost	Annual saving (R)	Payback period (Years)
Rainwater harvesting	300,000	14,553	21

Figure 10. Payback period of a rainwater harvesting system at the school.

Figure 9 shows that the proposed system could achieve annual savings of around R14,552, based on a water tariff of 14.08/kl and a monthly fixed charge of R149.70 (Kouga, 2021). This would be slightly reduced as the cost of maintenance and electricity for pumps are not reflected. Using this level of savings would provide a payback period of 21 years, as shown in Figure 10.

The above calculations are based on a normal year, where emergency or punitive tariffs have not been applied. Punitive tariffs are much higher than normal tariffs, for instance, the City of Cape Town's emergency tariff for schools is R41.67 per kl for water (City of Cape Town, 2021). If there are severe shortages and water tankers are required, costs increase further. For instance, the rate for the delivery of water is R1,576 per kl in Buffalo City in the Eastern Cape (Buffalo City, 2021). Under these types of conditions, payback periods for the rainwater harvesting system drop markedly and would be under 10 years.

5 Discussion

The results indicate that a rainwater harvesting system could enable the school to be self-sufficient in water. This, however, requires highly efficient fittings and careful use of water. Conventional fittings and use of water result in water consumption levels of 6,715 litres per day, or about 32 litres per person per day compared to the 3,775 litres per day or 18 litres per person per day for efficient fittings and water use. The figures for efficient use are similar to consumption rates of 20 litres per person per day used in dry areas such as Namibia (Sturm, *et al.,* 2009).

In the proposed system, rainwater is captured off roofs and if you divide the catchment area (2,140 m^2) by the number of occupants (210), there is about $10m^2$ of catchment area per occupant. The rainwater harvesting system captures significant amounts of water from these surfaces and stores this. The entire volume of storage divided by the number of occupants indicates that 1,000 litres are harvested and stored per person. This amount may be reduced through modelling at a finer grain, for instance, through the use of daily rainfall data. Care however should be taken to ensure that a buffer is retained in case of prolonged dry periods.

A review of the findings indicates that for a school to be water neutral or water positive, in this climate zone the following factors must be in place. Firstly, water consumption at the school must not exceed 20 litres per occupant per day. Secondly, there must be at least $10m^2$ of roof catchment area per occupant. Thirdly, there must be at least 1,000 litres of rainwater harvesting storage volume. The relationship between these factors is shown in Figure 11.

Number of occupants	Maximum daily consumption of water (Litres)	Minimum area of catchment surface (m2)	Minimum rainwater harvesting volume (litres)
1	20	10	1000

Figure 11. Relationship between occupants, water consumption, catchment area and rainwater harvesting volume

A review of rainfall patterns in other areas of South Africa show that dry seasons can be more severe and longer in other areas. For instance, Figure 12 shows that there are 5 months of the year with less than 20mm of rain in areas like Pretoria, in the North of South Africa. This means that levels of stored water must be significantly higher and there may be insufficient area for a roof-based rainwater harvesting system to provide for all the water needs at the school.

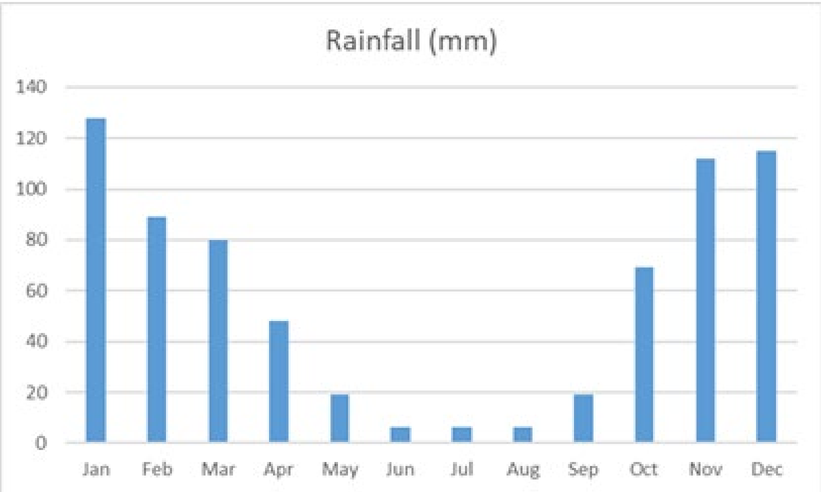

Figure 12. Monthly rainfall in Pretoria, South Africa

Financial analysis shows that the payback period for the proposed rainwater harvesting system is over 21 years. Other studies indicate that around 20 years has been the norm for rainwater harvesting systems (Imteaz *et al.,* 2011; Roebuck *et al.,* 2011). Roebuck *et al.,* (2011) confirm that this type of payback period does not make business sense where there are reliable municipal water supplies.

However, where water supplies are unreliable, an off-grid rainwater harvesting system provides significant value by enabling business continuity and avoiding disruption in times of water shortages. Emergency or punitive tariffs during drought periods also have a marked effect on the business case for rainwater harvesting systems enabling this to drop to less than 10 years.

The most valuable impact of net positive water systems is that education disruption and school closures are avoided This precludes a wide range of potential negative impacts associated with poor education that would impact learners, parents, and the local economy.

Amos *et al.* (2016) suggest that rainwater harvesting systems in developing countries can have benefits that are often ignored in developed countries such as increased flexibility during water restrictions and the creation of local jobs. Rahman *et al*., (2012) argue that benefits such as business continuity provide a strong rationale for rainwater harvesting systems to be subsidised.

6 Conclusions and Recommendations

The study investigates the potential impacts and feasibility of installing a rainwater harvesting system in a school in a drought-stricken area of South Africa. Findings from the study indicate that rainwater harvesting systems can be easily designed and installed cost-effectively at a school. This system harvests water from roofs of school buildings, stores this water in a system of tanks and uses this water for drinking, cleaning, and flushing toilets.

Modelling based on conventional fittings and water use indicates that water consumption per person per day under conventional conditions is approximately 32 litres and that a roof-based rainwater harvesting system in the selected climate will not meet this need. However, if more efficient systems and careful use of water are applied to reduce water consumption to 18 litres per person per day, it appears that a roof-based rainwater harvesting system can meet all the water needs of the school and result in the school becoming water net-positive.

An analysis of the financial viability of the system indicates that the payback period is approximately 20 years. This suggests that there is not a strong business case for a rainwater harvesting system in schools where there is a reliable, affordable municipal supply. This however changes when water supplies become unreliable and result in the school having to close. In this situation, the case for rainwater harvesting systems becomes much stronger as it enables schools to remain open and continue to achieve their main function which is to deliver good quality education.

The study shows that it is possible to develop a simple roof-based rainwater harvesting system for a school in a drought-stricken area that meets all its water needs. This is a significant finding as it presents an important way of avoiding disruption and closures of schools that can negatively affect educational outcomes. It is recommended that further research in this area be carried out to develop guidelines for the development of rainwater harvesting systems for schools in drought-stricken areas.

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Smart Cities; an IoT Enabled Transformation in Dubai, UAE

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Abstract

The use of the "Internet of Things (IoT) enabled smart devices" is changing the era of city development globally. Many cities like New York, London, Songdo and others have advanced steps to achieve digital smartness. However, some cities like Dubai are still at the model or prototype stage. This motivated the need for a preliminary study to highlight how Dubai can achieve the world's smartest city status through digitalisation and information management.

The essence of this research is to highlight the input of the Internet of Things (IoT) as an enabler towards the success of achieving smart city status in Dubai. The study adopted both quantitative and qualitative research methods over a target population of 145 people. It employs an extensive review of existing literature relevant to the topic to expatiate the benefits and challenges of smart cities and information management in such scenarios. With a 67.5% survey response rate; for Dubai to achieve high rankings in the smart city industry, it will have to increase the reliability of the public transportations like buses and automated Metro systems, increase human involvement in the decision-making process as well as ensure that open data systems available are secured to prevent data breach issues. This exploratory study will require a more structured approach with relevant stakeholders to validate the findings.

Keywords: Internet of Things, Smart Cities, Sustainability

1. Introduction

The facilities management industry contributes significantly to the development of organisations, cities and countries. With a market size ranging from £4.5 to £187 billion, the industry's maturity has resulted in its capability to manage technology systems, property, and associated staff to achieve higher performance standards (Wiggins 2014).

Smart cities are cities whose governments have made a credible investment in human efforts, transport, economic affairs, and the implementation of information communication technology (ICT) infrastructure to steer sustainable developments and improve living standards (Centreforcities, 2014). Recently, the concept of having smart cities and facilities interconnected and managed via one server with minimal human interactions known as the Internet of Things (IoT) has gained popularity and deserves worldwide attention (Wortmann and Flüchter 2015).

Increased urban development to mega-cities has been identified as a plan towards achieving sustainability under a collective strategy. Integrating facilities via a smart grid, improving the existing national electric grid, targeted towards meeting the future's demands and achieving sustainability through energy optimisation is another aspect of smart cities that require particular attention (Bushby 2011). In line with Dubai's Vision 2021 and Smart Dubai 2021 strategies, Dubai aims to achieve a total smart city status by 2021 (SmartDubai 2017).

Comparing Dubai to New York, which currently holds the position of the world's smartest city, a gap has been identified between both cities' implementation processes. The use of a human-centred approach, women empowerment, strategic solutions provision and the cooperative collaboration between all state departments can be attributed to New York's success. Dubai is closely following in the footsteps of its counterpart with the inclusion of PPP's as the structural framework for this initiative (Architecture 2017); however, having collaboration is the reason for this gap.

The growth of the IoT world has become prevalent. Therefore, it is incumbent on the managers of this industry to sharpen and develop appropriate techniques that will facilitate remote monitoring and management while reducing the maintenance costs to be incurred.

2 Literature Review

2.1 IoT and Smart Cities

Between 1990 to the early 2000s, the internet, which many uses to send data from one location to the other had its speed being equated to the success of liberal democracy (O'Maley 2016). However, incorporating IoT has eliminated the traditional architecture of the initial internet system by enabling communication over simple devices like sensors and household appliances, including the refrigerator and coffee machine (daCosta 2013).

IoT integrates a more significant quantum of varying end systems with open access to other data facets to facilitate the generation of a surfeit of digital services for use (Zanella *et al.* 2014). Smart City developments are currently fronted by system architecture developed by IT giants such as IBM, Oracle, Honeywell, Siemens and others who seek to develop new and improved ways for cities to function.

Smart cities operate across six major disciplines; mobility, governance, living, economy, people and the environment (Giffinger *et al.* 2007). For a city to be recognised as smart, it should have a higher number of its infrastructure connected to the internet via a smart grid that combines both intelligent architecture and electricity to develop a two-way communication and electricity transfer approach (Bushby 2011). This facilitates a remote-based control system equipped with faster fault identification and an improved maintenance culture system.

2.2 Motivators and Drivers of IoT Technology

IoT is considered not only a technology upsurge but an economic phenomenon within the global information pool following closely after the development of the general internet (Chen *et al.* 2014).

Silverio-Fernández et al. (2018) propose that the technology world has witnessed industrial revolutions dating back to 1784, where steam power engines were developed as a means of generating energy for use, to 1870, where mass production was mainly achieved using electric energy and 1970, which introduced IT systems and programmable logic controllers to facilitate the automation of various processes. The challenge of obtaining real-time data for assessment still hangs on, resulting in the fourth revolution. IoT and cyber-physical systems were developed to enable communication over wider areas with a larger number of devices providing real-time data.

Smart initiatives can be classified mainly under two broad headings; the top-down or technology centred approach and the bottom-up approach. The former employs the strategy of achieving smartness by integrating gathered data from different sensors in one virtual platform to enhance efficient city operations management (Centreforcities 2014). Cities developed via this approach include Songdo city, South Korea and Masdar City in the United Arab Emirates.

With the bottom-up approach, the emphasis lies on utilising new and improved technology and readily available open data to encourage the occupants to partake in their city's developments with the appropriate authorities (Centreforcities 2014). IoT's goals include identifying, tracking, managing and monitoring systems via information exchange and communication through well-established sensor devices (Chen *et al.* 2014).

2.3 Investing in Smart City Initiatives; The Opportunities and Challenges for Urban Development

To actualise a smart city, city administrators rely on partnerships with the private sector to adequately fund any smart city initiative (Moir, Moonen & Clark 2014). Smart projects are expected to reduce the actual and perceived investment risks, attract long-term finance, facilitate project gathering procedures to generate the necessary funds at a lower transaction cost and broaden the scope of balance sheet systems with private processes (Sergio, Medarova-Bergstorm & Vasileios 2013).

Fig 1: Funding smart cities

Source: (Galati 2017)

The government's coffers usually are the principal source of financial resources for smart projects. Governments invest in the urbanisation as it creates a positive image of the leaders in terms of transparency with the citizens, though it may involve a higher amount of bureaucracy in securing state funds (Galati 2017). This is usually popular with wealthy cities such as Dubai and Vienna due to their economic stability (Moir, Moonen & Clark 2014).

Public-Private Partnership (PPP's) exist between technology companies and the local governments. The government may retain ownership of the asset while the other party maintains and manages the asset for a stipulated amount of time (Galati 2017). This has been illustrated in Fig 1.

Other governments adopt the principle of user charges and pay per performance where the smart project is designed with a repayment plan disguised as user charges. Examples of such initiatives in Dubai are the onboard Wi-Fi charges of $4.99-10.99 on Emirates Airlines as well as the Dubai metro Wi-Fi initiative at metro stations in Dubai where users pay either Dhs20 or Dhs50 to enjoy uninterrupted internet on their journeys (Emirates 24/7 2018; Emirates 2018).

One may also obtain the necessary funding for these initiatives from grants and mutual loans obtained from other countries (Frost & Sullivan 2017). Maddox (2016) highlights the risks associated with investing in such initiatives. He proposes that projects with an uncertain return on investments should be financed via the traditional options such as owners capital, loans and grants, preference shares, venture capital. However, they are lower levels of debt financing.

2.4 Business Opportunities Associated with Smart Cities

Smart cities thrive on business value (Krotov 2017). The existing models tackling the pending wicked problems are not interconnected to their full potential creating a lucrative business opportunity for investors to develop a single platform for these integrated solutions (Marginalia 2018). Artificial intelligence is one of the most funded technologies drawing many investors to make a substantial profit (Frost & Sullivan 2017).

Urbanisation of cities contributes significantly to the country's Gross Domestic Product (GDP). Business model creation such as Build Own Operate (BOO), Build Operate Transfer (BOT) enables authorities to create partnerships to acquire funding for their smart projects (Forbes 2014).

By providing access to resources via car and accommodation sharing, public charging stations and the provision of micro-grid energy networks for homes, governments will be able to supply the demands of the citizens cost-effectively without expending more on the extension of physical infrastructure (Drubin 2017).

2.5 Challenges Faced in the Operation of a Smart City

Smart city management is a herculean task involving many processes. In implementing a top-down management approach, the risk of having dead creativity as a result of corporate giants monopolising the city's smart developments comes off as a challenge hindering the city's progress resulting in the inability to effectively transfer thoughts to actions and detrimental investment decisions (Aguinaldo 2015). Similarly, with the bottom-up approach which is represented by communities and other smaller-scale initiatives, there is the issue of difficulty in advancing the generated solutions as well as assessing the actual outcome of these solutions (Höjer & Wangel 2014).

In managing the wireless sensor networks across the smart grid, the most popular challenges faced include failures in the communication networks, difficulties in replacing parts on the network system, uncertain deployment of network topology as well as allocating the necessary resources for the smooth operation of communication networks (Minh *et al.* 2013).

Traffic congestion management results in an increased number of road accidents and robberies, financial losses due to traffic delays, inability to effectively monitor and disseminate traffic information from the traffic management system causing overall user discomfort (Djahel *et al.* 2015).

2.6 Sustainability in Smart Cities

The idea of smart sustainable cities sprung up as a solution to deal with three major goal trends of urban development advancements in Information Communication Technology (ICT), urbanisation and the widespread of environmental sustainability (Bibri 2018).

Knowledge creation during the city design should cover the three pillars of sustainable development, which are economic, social and environmental (Höjer & Wangel 2014). Economic sustainability can be achieved in such an instance through data monetisation, crowdfunding, sponsorship and facilities leasing (Galati 2017). Regarding environmental sustainability, energy conservation and air quality improvements are of great concern in urban development as little errors become very costly (Girardi & Temporelli 2017).

On the social level, governance and transparency in the implementation of smart policies drive sustainable development. Citizen-driven smart cities yield more positive results as compared to other initiatives since real-time data is obtained from their input to be used for developing innovative solutions (Bolívar *et al.* 2016).

2.7 Dubai as a Smart City

Dubai has been ranked as a model smart city due to its pioneering developments such as driverless cars, silent airports, traffic and waste management systems, social robots among others. The city is an upcoming prototype with the intention of achieving total smart status before 2030 (Waheed 2018).

This is an initiative of His Highness Sheikh Mohammed bin Rashid Al Maktoum the ruler of Dubai to tackle the major areas of transport, communication, the economy, city planning and infrastructure (Government.ae, 2018). Smart Dubai boasts of more than 1000 connected smart devices as well as over 200 data sets to facilitate the benefits of shared data for Dubai's development. This is governed by six major domains; transparent and effective governance, proper city management, faster deployment of IoT solutions for wicked problems, Monetisation of the technology ecosystem, city sensors as well as addressing matters of risk and security of the deployed sensor networks (SmartDubai 2017).

Once completed, the Dubai Silicon Park located in Silicon Oasis will be recognised as Dubai's first smart city. It makes use of electric cars and bikes as the primary means of transportation, a control centre to monitor and gather data for the city's management, free Wi-Fi and an environmentally friendly community as per the international LEED Standard and green building regulations in the UAE (DSOA n.d).

3. Research Methodology

A structured web-based survey was sent out to 145 industry professionals to ascertain key facets of IoT and Smart Cities in this region. This random sample size was obtained from data found on LinkedIn and the Dubai yellow pages websites. Each person was contacted to ensure that they still worked in the construction and IoT industries to validate the data received. The survey questions adopted the 5-point Likert scale in order of importance as well as sections for the respondents to fill in with their viewpoints.

To ensure that the survey questions met the research requirements, A pilot study of 6 respondents was established to validate the questions relevant to the subject matter. After a successful pilot study, the survey went live on June 10, 2018, and was closed on July 12.

Ten structured interviews were also conducted with selected industry influencers, IoT service providers as well as Dubai Silicon Oasis executives to support the qualitative research strategy.

The results were analysed with the Statistical Package for the Social Scientists (SPSS) software and represented in the form of charts and tables for easier understanding.

4. Data Analysis and Discussion of Findings

The survey sought to identify the extent of IoT transformation in Dubai. This questionnaire was administered to 145 people comprising of construction, IT and facility managers registered in Dubai and received a high response rate of 67.5%. This high response can be accounted for since the smart cities concept is fresh and of high interest. The IT sector contributed the highest to the survey with a percentage of 29% increasing the validity of the survey as IT is a driving force for smart city projects. Table 1 and 2 displays the respondents demographics:

Tables 1 and 2: Respondents demographics

Profession	Number of Professionals
Contractor	13
Project Manager	20
Quantity Surveyor	18
Facilities Manager	8
Engineer	10
Information Technology	28
Total number	**98**

Years of Experience	Percentage of Respondents
0-4 years	15%
5-9 years	33%
10+ years	52%
Total	100%

Fig 2 shows the survey also tracked the popular smart means of transport used by the respondents in terms of their importance. The electric vehicle received high nods for being the smartest option available, followed by the driverless metro and existing bus system.

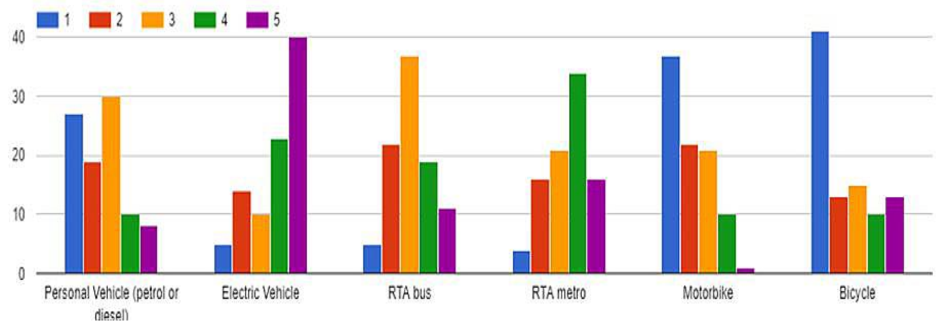

Fig 2: Popular transport options in Dubai

These shared provisions will go a long way to decrease traffic congestion, increase user happiness and savings. This also ties in the UAE smart vision to ensure that Dubai remains one of the worlds smartest cities.

4.1 Defining Themes of Smart Cities

As mentioned in Table 3, this section allowed the participants to select from a list of seven themes, which accurately defined a smart city to them. 65 responses were recorded here with IT being the greatest contributor (37 representatives), affirming the definition of a smart city as proposed by (Centreforcities 2014). Others believed that smart cities can be characterised by urban planning, transport, shelter and healthcare. All other themes aside IT play supporting roles in achieving the smart vision of any city, their omission will be detrimental to the citizens' well-being.

Table 3. Feedback on Smart City Themes

Theme	Frequency	Percentage
Shelter	4	4.0%
Waste Management	1	1.0%
Information Technology	37	37.8%
Urban Planning	14	14.3%
Transportation	5	5.1%
Healthcare	3	3.1%
All themes	34	34.7%
Total	**98**	**100.0**

Evaluation of Dubai's Current Position in Smart Development

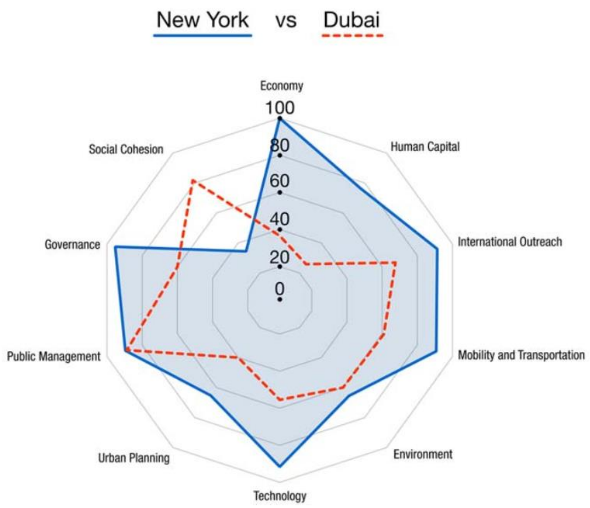

Fig 4. Spider Analysis of New York Vs Dubai Smart Achievements

Source: (Architecture 2017)

A practical analysis had to be made to identify Dubai's position as against the smartest city in the world (New York). As showed in Fig 4, New York recorded very high points between 80-100 for its economy, international outreach, mobility, technology, public management and governance policies. Dubai on the other hand scored lower points recording the least for human capital (25) and the most for social cohesion (81) where New York fell short (less than 40). However, New York's success is attributed to its coordination, commitments and partnerships between public and private institutions and the focus on human capital involvement. To achieve this global recognition of smartest city, Dubai launched the future accelerators program in 2016 and the happiness initiative to find positive solutions to the city's challenges from both the public and private perspectives (Architecture 2017).

4.2 Funding Options for Dubai's Adoption

As per literature, funding the affairs of a smart city project can be a herculean task for city administrators as great concern arises in the area of sustainable urban development and minimising the emissions released into the atmosphere. As innovation is mandatory for such projects, it was expedient to analyse the options available for Dubai's adoption. Majority of the respondents agreed with the use of PPP's as the major funding source for Dubai's projects, as it fosters corporation between both sectors and generates a larger pool of resources with quality end products.

4.3 Sustainability Ratings

In recent times, awareness has been created on the need to protect our environment for the future. Dubai's high carbon footprint has created the necessity for sustainability and smart developments. 56.1% agreed that smart devices will help Dubai perform better in the area of sustainability, which will attract more investors into the country to boost the economy and foster better economic ties.

4.4 Data for Urban Development

74.2% of the respondents agreed to the use of end-user surveys, software applications and living labs as the major sources of obtaining data for urban policy development. Currently, the Dubai happiness meter combines both surveys and software to measure end-user happiness throughout Dubai and it also gathers data necessary to eradicate areas that counter the citizen's happiness. Dubai Design District also acts as the main living lab for Dubai in pooling resources and innovative ideas to solve the city's problems.

The government currently provides an open data service for its citizens and numerous visitors with high-level transparency and accuracy. This open data program is targeted towards human development as a public participation initiative.

4.5 Dubai's Smart City Initiatives

This last segment of the survey investigated the smart city initiatives available in Dubai presently. This sought to answer the objective of this research which was to identify the level of adoption of IoT transformation in Dubai's projects. the most popular smart projects per the responses were:

- Tier 3 Data back up by IBM and Oracle
- Dubai International Airport E-gate immigration checking
- Smart Parking and Smart Sensor traffic lights
- Smart Home Security System by Dubai Police

- Dubai RTA Metro, RTA Bus tracking system via RTA mobile application
- Dubai Happiness initiatives, UAE Wi-Fi and Paperless Strategy
- U-Drive and Elkar car rental system
- E-payment systems for city services
- Silicon Oasis Smart City

The benefits derived from these smart projects included parking, payment, information access, public engagement, transport energy efficiency, traffic congestion and internet connectivity which had all been made easier and efficient and convenient with these provisions. However, 27 respondents mentioned the challenges they faced with these IoT projects which were:

- RTA Bus Timing Schedule Delays
- System failures resulting in M-parking fines
- System complexity at Dubai Mall REEL cinema with order placement, payment and collection.

Although these initiatives came with some challenges, the benefits greatly outweighed the negatives which goes to prove that smart projects are beneficial to the city's economy.

4.6 Qualitative Discussion of Interview Results

As the city gears up towards hosting the Expo 2020, it was necessary to interview professionals located in Silicon Oasis (Dubai's premier smart city), and IoT service providers. Ten senior professionals were interviewed to ascertain Dubai's current level of smartness and their observations on the integration of connected technology into Dubai's infrastructure as an IoT enabled transformation for future success.

4.7 Uses and Benefits of IoT

All the interviewees were of the notion that IoT was an interesting concept for adoption. However, 2 reiterated that access to real-time data at any time as the most beneficial. They further expatiated that data could be used by different organisations for their personal and business benefit like weather forecasts and building maintenance. Another indicated that the Return on Investment for IoT technology is high now as a lot of cities have made significant investments in IoT and are reaping the benefits.

4.8 IoT Associated Risks

Here, the respondents were in unison regarding the fact that IoT's biggest threats are data breaches and security. One indicated that IoT collects both personal and public data, which will have detrimental effects on the individual and state should it fall into the wrong hands. An executive from the Dubai Silicon Oasis Authority went on to highlight that even as Dubai currently has the Dubai Data policy, which is similar to the General Data Protection Regulation, which was implemented very recently (May 25 2018) in the European Union, people will still have to be mindful of the kind of data they put out in public.

4.9 Evaluation of Dubai's current status and future predictions.

Here mixed ratings were recorded from the respondents. However, the most popular rating was 3 out of 5 mainly for the following reasons:

- Although there are other smart projects like the metro and the smart traffic lights, Until Silicon Park is completed, it will not be prudent to rate Dubai 5 out of 5.
- The existing RTA bus system cannot rely on 100% as the bus timing schedules are not always exactly as displayed on the internet or RTA App. There is usually a 5-10-minute delay which is not conducive for the commuters. In Singapore, headlines are made when the bus or train system is delayed by 2 minutes, and Dubai needs to improve on this to obtain higher smart ratings.

They also commended the existing maintenance culture in Dubai as residents and visitors could easily log in complaints to be rectified in no time. The respondents also commended the emergency response times. Looking at the future of Dubai as a smart city, all respondents agreed that the city is gearing up for success. One respondent mentioned that with the upcoming expo in 2020, the city would be transformed to a greater extent digitally, and more businesses would be drawn to this city.

5. Conclusion

Based on the analysis of the field results, it can be concluded that the adoption of smart projects for urban development together with a participatory governance system is a step in the right direction for Dubai and other cities as it satisfies the exact needs of the citizens, Smart systems require end-to-end connected devices which will obtain and exchange data between servers.

Urban IoT projects are currently in a large positive market worth millions of dollars. However, critical thinking and planning need to be made to prevent the liquidation of resources as the return is anticipated to take longer despite its positivity. In addition, the complexity of the systems can be made more user friendly to avoid redundancy and increase work and energy resource efficiency to ensure sustainability.

Lastly, the majority of the people of Dubai are satisfied with the smart projects ongoing and they seek more IoT enabled transformations in the city as the anticipated Return on capital investment is positive.

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Track 2

Cost Benefit Analysis and Value Added

Smart and Sustainable CAPEX Planning to Develop New Infrastructure. Case Study: Hosting Mega Event - Dubai EXPO 2020

Critical Success Factors towards Collaborative Road Infrastructure Projects Delivery in Tanzania

Asset Maintenance and Operation

Terrestrial Laser Scanner Analytical Modelling towards Effective Scan Area Planning for Damage Detection on Structural Members

Assessment of the Variation in the Maintenance of HVAC Component Units and its Energy Consumption Implication

Management of Recovered Wastewater for Passive Irrigation of Buildings Green Landscaped Areas: Blue/Green Roof Subterranean Water Management System

Smart and Sustainable CAPEX Planning to Develop New Infrastructure. Case Study: Hosting Mega Event - Dubai EXPO 2020

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Abstract

The availability and quality of infrastructure are considered as critical elements and pillars to ensure high standard of living for any city. However, securing budget for investment in new infrastructures or upgrading existing ones is a challenging task for governments, therefore, the competition between cities worldwide to achieve and maintain a distinguished place in quality of living is tough. Nevertheless, infrastructure projects are considered as catalyst for economy as it is linked to different industries and businesses. Hosting global mega event, such as, EXPO, Olympic Games & FIFA World Cup is a national ambition for any city to mark its position on the globe, furthermore, it is an opportunity to attract investment and secure budget in building new infrastructures, buildings and facilities to improve the quality of living. This paper explores the efforts made by Dubai government to deliver Expo 2020 event and the governance model adopted by Dubai emirate for planning and management to assure successful delivery of the event. The research work will shed light on sustainability model implemented by different authorities to deliver the required projects for the event, as well as, the long lasting Legacy, in addition, the paper will explore the sustainability concepts to maximise the benefits from investment in infrastructures and buildings and the generation of new development, urban areas and places of interest. The main objective of the research work is to present Dubai model and methods applied to balance different factors to deliver the sustainable event of Expo.

Keywords

Hosting mega event, legacy, sustainability.

1 Introduction

Large scale mega events such as the Olympic Games, FIFA World Cup or World Fair EXPO draw the interest of massive numbers of people. They are intended to encourage local and regional economic development by attracting investment, tourism, and media attention for the host city. Host cities generally attach great importance to factors such as the event's economic implications, event-related income, urban development and regeneration, building and upgrading infrastructure, providing a transportation system capable of transporting the expected numerous visitors to and from the event location and the development of tourism (Taha & Allan, 2019). Researchers stated that most cities aim to maximise the benefits of hosting mega-events to develop infrastructure and push urban renewal, often through leveraging funds that would not be available otherwise (Grix, 2013),

(Hiller, 2000), (Hiller, 2000) & (Smith, 2012). Therefore, mega event is considered as great opportunity to foster development and raise its international profile, enrich its reputation, and accelerate improvement of infrastructure, and related urban development. Besides, it boosts construction industry and generates employment, during the event and post event, and improves global business and investment environment of the country.
Contrary, hosting mega event is considered as challenge for governments to secure the required budget and resources to successfully manage and deliver the associated projects with the event, hence, sustainable and smart plans are required to maximise the benefits from investment in constructing new building, infrastructures and facilities and upgrading the existing ones. The integration in planning for short-term event and long-term legacy is an example of sustainable planning. The consideration to maximise the benefits from investments by introducing plans for legacy and generation of new urban development will add great value for the city.

2 Literature Review

In dynamic and fast-growing world, the demand for urban development, availability of transportation, provision of accessibility and flexible connectivity are vital for people to maintain business continuity, high-quality lifestyle and addressing the growing needs for communities and cities.
It is widely recognized that hosting mega event will place critical demands on urban development, its transport system and other infrastructure. Often, this will require improving existing infrastructure systems by adding new infrastructure and upgrading the capacity of the existing ones. Mega event has often been described as a lucrative tool for place promotion and marketing and as a key link between the local and the global. Chalkley and Essex (Chalkley & Essex, 1999) stated that different cities have shown increased interest in the idea of promoting urban development and change through the hosting of major events. This approach offers host cities the possibility of 'fast track' urban regeneration, a stimulus to economic growth, improved transport, and cultural facilities, and enhanced global recognition and prestige. For instance, South Korea is an example of utilizing the opportunity of hosting mega event as effective pathways to mega urban redevelopment, such as, developing a new national capital Songdo in a tight timeframe of the event (Surborg, et al., 2008) and (Short, 2008). Chen and Spaans (Chen & Spaans, 2009) concluded that planning for hosting mega events must be interwoven with urban economies and urban development to create the legacy. Owing to its use of the Olympic legacy, increased capital flows and its improved attractiveness as a city, Barcelona was able to boost its economic growth, enhance its image and transform itself into a globally competitive city. Barcelona's success is one indication of the significance that the Olympic Games can have for urban development practices and urban policy in host cities, and, equally, the importance of understanding the Olympic Games from an urban development perspective (Chen & Spaans, 2009).
The Olympic Park site at Stratford, London is one of best examples of urban regeneration initiative and sustainable development that resulted from hosting the 2012 Olympic Games in London (Richter, 2012). The land of the Olympic park was used as landfill after the 2nd World War bombing of London, and was compromised by poor drainage issues, with utility and transport infrastructure crisscrossing the site resulting in its functional fragmentation. The objective of using the Stratford site was to provide quality infrastructure, so, the value of the site and its surrounding areas was to be improved socially, physically, and economically. The key success for London's 2012 Plan was to arrange and maximize the efficiencies of its transport infrastructure to serve the Games and assist in regenerating the area around the Olympic Park afterwards (Richter, 2012).
In 2004 Athens hosted the Summer Olympics. Due to the city's urban form and lack of large parcels of available public land, Athens had to spread out its Olympic venues across the Attica Plain. This was problematic due to the notorious traffic congestion facing Athens and the limited existing public

transport infrastructure within the city. Thus, by agreeing to host the Olympic Games, Athens embarked on a large scale of transport investment. The direct and indirect investments in transport infrastructure included a new international airport, two metro lines, a tram system, and a suburban railway. All these infrastructure improvements were built with the goal of making transport more efficient during the Olympic Games (Richter, 2012).
Nevertheless, other examples of hosting cities revealed lack of consideration for sustainability and planning for future, therefore, huge financial risk was imposed on economy, as a result of investing capital in underutilized developments and infrastructures, such as the case of Montreal's 1976 Summer Olympic Games, where the mega event saddled government with massive debts and creating potential urban blight with underutilized assets or white elephants (Taha & Allan, 2019) and (Taha & Allan, 2020). Similarly, Sydney Summer Olympics in 2000 was a significant catalyst for urban infrastructure development that includes better transport connectivity, capacity expansion of Kingsford Smith International airport, capacity improvements at its main rail hub, Central Station (Richter, 2012). The 2000 Summer Olympics Games reinvigorated and rehabilitated part of Sydney that was largely brownfield land with little appeal to the community, so that certainly is a lasting legacy of the Games. However, it is worth noting that the Homebush Bay site is not quite what the State Government wanted it to become with it being unable to capitalize on tourism and only achieving partial success in transitioning itself to an office park precinct. Additionally, many of the sporting facilities where surplus to requirements post Olympics, and the Olympic Stadium was downscaled immediately after the Games and is now planned to be replaced with a new up-to-date stadium (Taha & Allan, 2019) and (Taha & Allan, 2020).

3 Research Methodology

The research methodology is based carrying out several site visits and interviews with local authorities such as Expo 2020 Office, Roads & Transport Authority RTA and Dubai Municipality DM to collect the required data and information for the research work. The collected data and information are studied and analysed to shed light on the efforts made in Dubai to deliver the event and plan for the lasting legacy. Dubai model in management and governance will be explored and presented as benchmark for other cities with lesson learnt form Dubai experience during preparation period for the event. Below list of departments that were approached during the course of collecting research data:

1- Dubai Expo 2020 Office
2- Roads & Transport Authority RTA (Rail Projects Planning & Developments Department; Transportation Strategic Planning Department; Road Department; Traffic Department)
3- Dubai Municipality DM (Drainage & Irrigation Department, Infrastructure Services Sector)

4 Dubai Expo 2020 - Governance Model.

4.1 Corporate Governance - Statutory and Legal Background:

In accordance with hosting requirement of Expo, the UAE Government has developed the necessary legal, financial, and organisational measures required to organise and host the event successfully. In 2013 the Dubai Government established the World Expo 2020 the Higher Committee (Dubai_EXPO2020, 2020) and (Dubai Expo 2020, 2018). The Higher Committee was formed to centralise strategic decisions and oversee the overall planning and delivery of Expo 2020's requirements and activities. The Higher Committee established the following Specialised Committees to ensure efficiency and transparency through the committees' direct supervision on all funding, procurement and contracting processes. To support the higher committee to discharge their duties, other entities were formed under the higher committee, namely, the Bureau and the Company as shown in figure 1 below.

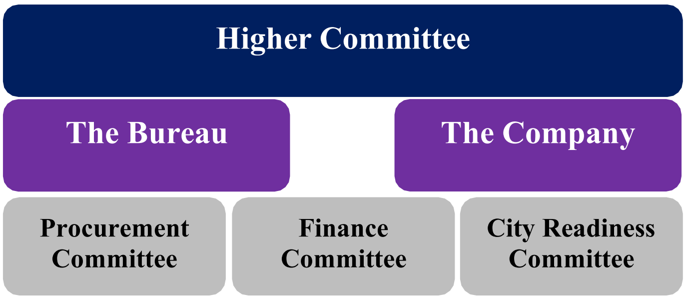

Figure 1. Dubai Expo 2020 Governance Model (Dubai Expo 2020, 2018)

4.2 The Bureau

Following the higher committee in hierarchy, the Bureau of Expo Dubai 2020 was formed and chaired by the UAE Minister of State for International Cooperation, as the Director General of the Bureau. As a government entity, the Bureau acquires its legal and financial jurisdiction directly from the Government of Dubai and acts as the executive arm of the Higher Committee and in charge of, but not limited to, functions included: Supervising the delivery of Expo 2020; Liaising with relevant government entities to ensure the availability of infrastructure for hosting Expo 2020; Coordinating with the relevant entities to ensure that Dubai will meet all requirements from facilities, equipment, financial, artistic, media, security, economic and tourism resources to host the event; Coordinating with public and private entities, locally and internationally, on all matters related to Expo 2020; Advertising and marketing the event (locally, regionally and internationally); Attracting local, regional, international companies and entities to sponsor Dubai for hosting Expo 2020.

4.3 The Company

In order to assist with the operational delivery and hosting of Expo 2020 Dubai, the Bureau incorporated Expo Dubai 2020 LLC (the Company) to oversee the operational development of the Expo and support the timely reporting of information through the Bureau to the Higher Committee.

5 Sustainability Consideration - Event Buildings and Facilities

The 4.38 sq.km Expo 2020 site incorporates the Opportunity, Mobility and Sustainability Thematic Districts, all of which converge at the Expo central hub Al Wasl Plaza at the centre of the Expo site. The site also houses the Dubai Exhibition Centre, Route 2020 Metro Station, arrival plazas, parks, permanent buildings, approximately 30,000 car parking spaces, and other facilities. The Expo 2020 site and its infrastructure is designed to be the platform for this legacy. Expo 2020 has four key sustainability objectives include leaving a legacy of sustainable infrastructure and future-oriented sustainable practices, catalysing sustainability efforts in Dubai and the UAE, increasing public awareness by engaging society on sustainability principles and sustainable living, and developing sustainability solutions that are scalable, extending their benefits to the wider economy. The adopted sustainability strategy by Dubai Expo 2020 to deliver the event and the legacy is standing on six main pillars: 1) Retain expo phase road and infrastructure; 2) Retain existing assets; 3) Maintain key anchors/buildings; 4) Legacy phase land use transformation; 5) Promote green and public spaces; 6) Focus on public and alternative transport models (AECOM, 2019). The main goal of sustainable strategy is achieving KPI of 90% of reusing the site including the buildings and facilities, providing a lasting asset and legacy to Dubai. Table 1 below lists Expo 2020 Sustainability categories, Objectives and KPIs.

Table 1. Dubai Expo 2020 - Sustainability Categories, Objectives and KPIs

Transport	Encourage the use of sustainable, lower carbon transport by providing alternative transport options such as the metro and the Expo Rider bus service
	- Encourage significant shift from private vehicles to alternative transport options.
Energy	Reduce energy consumption
	- Reduce energy demand in buildings by 20% in comparison to international standards
Public Realm	Create people-centric, comfortable, and walkable spaces
	- Provide shading for 75% of primary walkways in Thematic Districts at mid-day peak. - Provide shading for 60% of hard landscaping areas and public open spaces at mid-day peak
Sustainability Awareness	Enable visitors, participants, and facility managers to appreciate, understand and contribute to the responsible use of resources.
	- 75% of sustainability features with educational awareness, collateral, or activities
Ecology	Enhance the ecological value of the site and promote local species
	- 50% of landscape plants (during Expo 2020) and 95% of landscape plants (post Expo 2020) are native and adaptive species - 95% of landscape area managed without the use of chemical pesticides, herbicides or fertilisers
Water	Reduce the demand on potable water systems and reduce water consumption
	- Recycled water is used for 100% of non-potable applications (e.g. irrigation, cooling) - Collect and use 95% of condensate water recovered from buildings - Reduce water demand in buildings by 40% in comparison to local standards
Materials	Minimise depletion of natural resources through design for reuse and Legacy
	- 90% of materials used in permanent construction to be retained for the Legacy - 75% of materials in temporary construction to recycled.
Waste	Minimise quantity of waste to landfill
	- 85% of waste segregated into different waste streams, during construction, operation & decommissioning, to allow for diversion from landfill
Operations and Management	Communicate sustainability progress and achievements in a transparent and stakeholder responsive way.
	- Achieve ISO 20121 Sustainable Event Management certification - Publish sustainability reports based on internationally recognised guidelines
Sustainability Certification	Demonstrate added value through sustainability certification of both horizontal and vertical infrastructure.
	- Achieve LEED Gold Certification for Expo building projects - Achieve CEEQUAL Excellent Certification for Expo infrastructure projects
Carbon	Minimise carbon emissions in Expo 2020 Dubai. KPI
	- Fully implement a greenhouse gas (GHG) mitigation and off- setting strategy

6 Infrastructure Projects

Dubai is the most populous city in the United Arab Emirates, it has the rapid urban expansion experienced since 2003 which has placed enormous pressure on existing infrastructure to the point where major upgrades are becoming increasingly necessary. In addition, Dubai emirate heavily invested in building new infrastructures and facilities required for the delivery of Dubai Expo 2020 in addition to the Legacy. According to BNC Construction Intelligence Report published on construction week website (Bhatia, 2018), the estimated cost of total projects linked to Expo 2020 for different projects being constructed across various UAE sectors can be listed below:

- Infrastructure and energy projects account for $17.4bn (AED 64bn)
- Housing projects are worth $13.2bn (AED 48.5bn).
- The BNC Construction Intelligence Report also stated that hospitality developments, such as hotels, and destination and theme parks, worth $11bn (AED 43.4bn) are under way.
- Other developments under construction around the Expo 2020 Dubai site include Al Maktoum International Airport's (DWC) Phase 1, worth $8bn (AED 29.4bn), and the Villages at Dubai South homes, worth $6.8bn (AED 25bn).
- Dubai Exhibition City, worth $6.6bn (AED 24.2bn)
- Dubai Metro Red Line extension to DWC, estimated to be worth $2.9bn (AED 11bn).

The sections below describe examples of mega projects planned and executed by different local authorities to shape the holistic image required for the delivery of Expo event, the Legacy and improvement of infrastructure for Dubai city.

6.1 Deep Tunnel Storm Water System – (DTSWS) DS 233

To address the infrastructure demand for development of new urban areas and regeneration of new land, Dubai Municipality carried out major projects that serve Dubai Expo event, the Legacy, surrounding areas and new developed and generated urban areas.

The Deep Tunnel Storm Water System is planned to develop and implement a long-term catchment-wide plan for capturing and conveying stormwater and groundwater flows to the Gulf from Expo site, Dubai World Central (DWC) and the surrounding areas i.e. the Legacy, Dubai South, Al Maktoum International Airport, DWC Commercial and Residential, and other adjacent development communities along the conveyance system route. The total coverage area of the project is approximately 490 km2, which is almost 41% of the entire existing and future urban area of Dubai as shown in figure 2 below (Dubai Municipality DS 233, 2017). As per DM, the total estimated construction cost of the project is approximately 6 bn AED that will be secured through cost sharing with developers by establishing a fair and equitable method for recovering costs. The project was executed in phases and the focus of the current phase was to serve EXPO and DWC areas with estimate construction cost of 2.1 bn AED (Dubai Municipality DS 233, 2017).

6.2 Dubai Strategic Sewerage Tunnel – (DSST) DS 215

The other important project carried out by DM is the Dubai Strategic Sewerage Tunnel. The project is currently in design phase. The project is established to expand and improve the existing sewage system of Dubai city including the new development of Expo site, the Legacy and DWC as shown in figure 3 below (Dubai Municipality DS 215, 2016). Once it will be announced for tenders, the estimated total cost of project DSST will be approximately 16 billion AED.

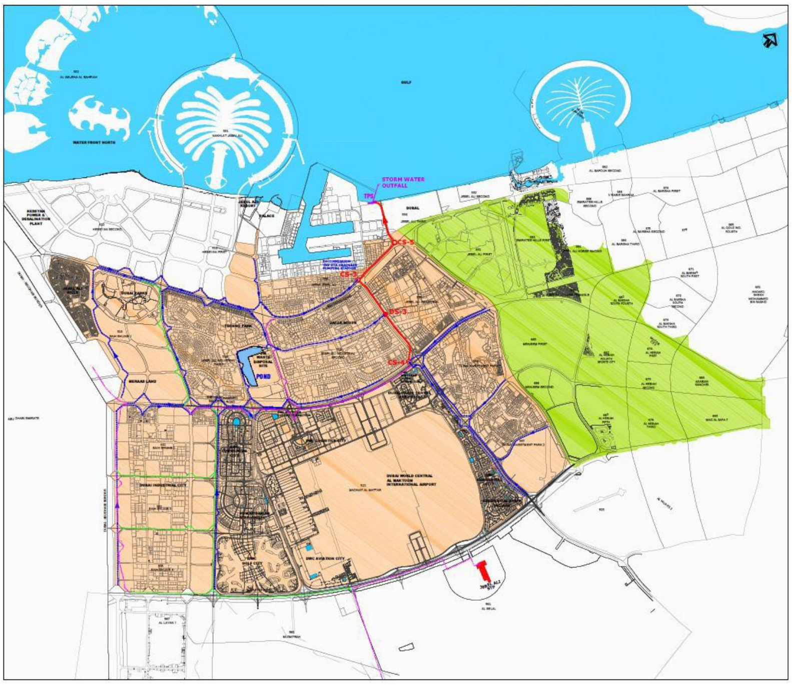

Figure 2. Key plan of project area of Deep Tunnel Storm Water System.
(Dubai Municipality DS 233, 2017)

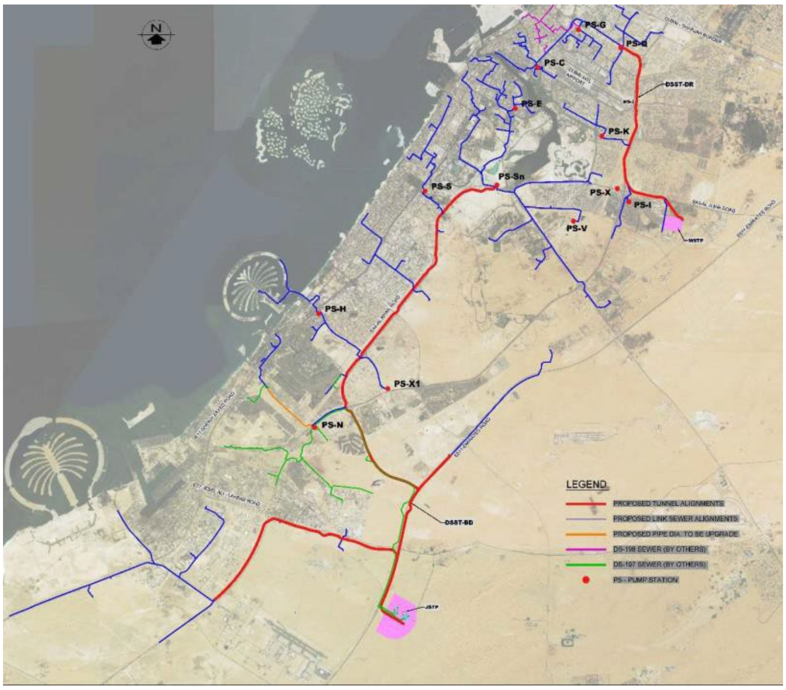

Figure 3. Key plan of project area of Dubai Strategic Sewerage Tunnel.
(Dubai Municipality DS 215, 2016)

6.3 Dubai Expo 2020 Roads Network Upgrade (R/1048)

The project objectives are to provide access to Expo site and meet the requirements of Dubai hosting the Expo 2020 exhibition. The project scope consisted of constructing road network surrounding Expo 2020 that includes new 9 intersections consisted of 64 bridges to provide grade separation for easy and smooth traffic, adding 38 km of roads for the surrounding area and expanding Expo road from 4 to 6 lanes in each direction to increase traffic capacity to 120,000 veh/hr. in addition to, providing 23 lanes for entry to Expo with traffic capacity of 34500 veh/hr, and 24 lanes for exit from Expo with traffic capacity of 36000 veh/hr as shown in figure 4 below. The total cost of 3.2 billion UAE dirhams (Dubai Expo 2020 - The Higher Committee for Roads and Transport, 2017).

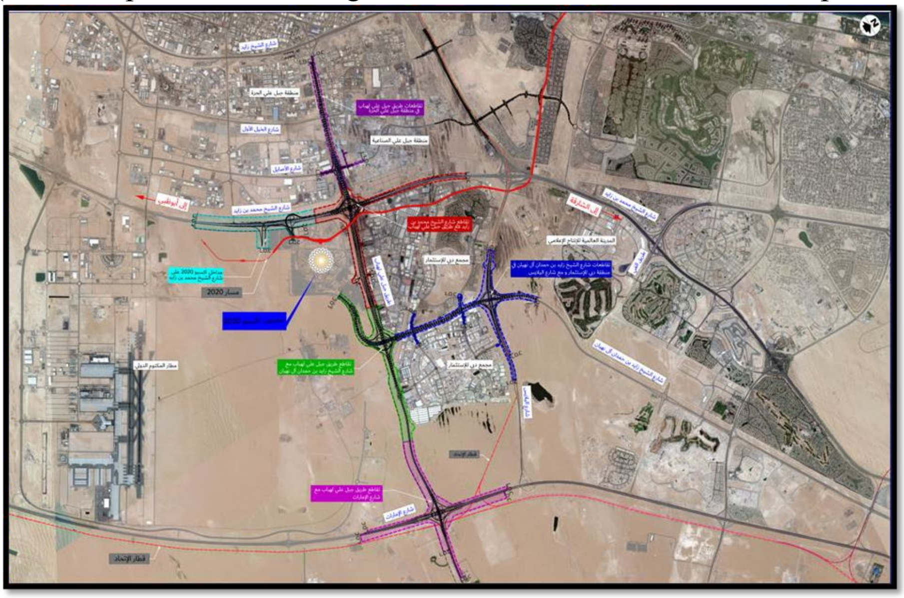

Figure 4. Key plan of project area of Dubai Expo 2020 Roads Network Upgrade (R/1048) (Dubai Expo 2020 - The Higher Committee for Roads and Transport, 2017)

6.4 Route 2020 Dubai Metro Red Line Extension

To ensure sustainable investment in building new public transport metro line, different alignments options were examined to obtain the optimum route that maximises the benefits from the investment as shown in figure 5 below (Transport_Model_Report, 2015). Each of the proposed alternative alignments were assessed and scored from 1 to 5 as score of 5 being the highest and a score of 1 being the lowest based upon each measuring criteria for the evaluation of the proposed alignments. The measuring criteria consisted of: Transportation & Future Developments; Route Insertion; Constructability; Sustainability; Cost; Operation & Interoperability

Among these different options, the selected alignment was measured as the best sustainable solution that is viable to serve local communities after the completion of the event. The total length of the line is 15 km with 7 station (5 overground and 2 underground). The estimated cost of the new metro line is approximately 11 bn AED. Route 2020 is planned to serve commercial and residential areas with medium to large densities population about 270,000. The capacity of the route is estimated at about 46,000 passengers per hour in both directions 23,000 passengers in each direction per hour. The number of users of the route is expected to reach 125,000 passengers per day in 2020 and will rise to about 275,000 passengers per day by 2030. It is anticipated that about 35,000 of Expo visitors per day will use metro station of route 2020 and this number will rise to 47,000 visitors a day during the weekend. These figures represent about 20% of the total number of daily visitors expected to visit Expo during the event. The alignment of route 2020 was coordinated with Al Maktoum International Airport to identify future extension of the route inside the airport. Route 2020 metro extension line will also serve as an integrated transport mode for the area and provide a link to the heart of Dubai.

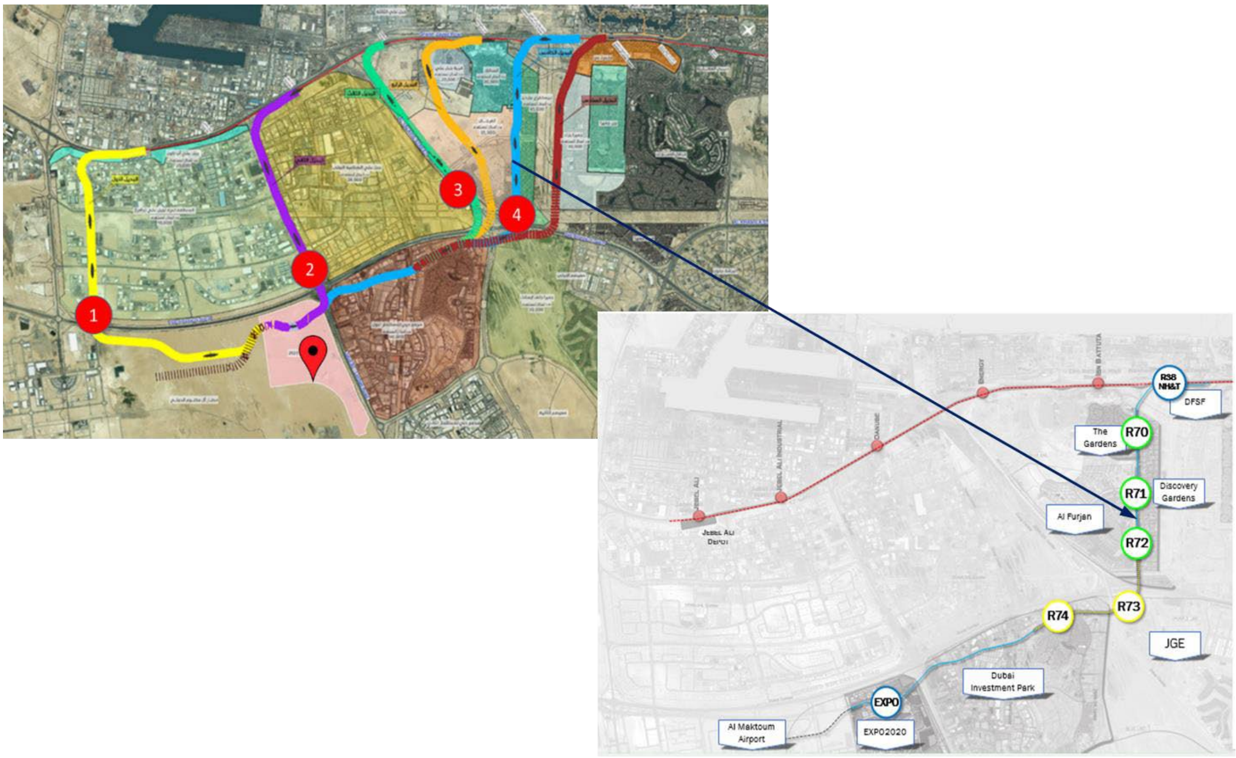

Figure 5. Alignment options for Dubai metro route 2020 and preferred alignment No. 4 (Roads & Transport Authority Dubai, 2015)

7 Findings and Discussion

The research work reveals that the UAE and Dubai Emirate have established a structured governance system and orgnastions that contain high profile managerial members form different authorities to facilitate decision making at high level of authority and ensure the successful delivery of the event. According to the adopted model by Dubai government to ensure sustainable investment, plans for Expo event were interwoven and integrated with future holistic development of Dubai emirate, so, the planned and executed mega projects to build new infrastructures and buildings will serve the short period event and address the demands for future developments of the city. For instance, about 90% of buildings and facilities planned for Expo will serve the objective beyond the event of the lasting legacy “District 2020”. In addition, the mega projects such as the new metro line, road network and strategic tunnels for storm water and sewer were carefully planned and agreed among the higher committee members to be executed to address the delivery requirements of Expo, future plans and city growth demand.
As for the sustainability model, clear objectives and KPI were set to deliver certain sustainability categories, the KPIs were continuously measured to ensure that all consideration are adhered to as per the set sustainability model.

8 Conclusions and Further Research

The research work explored the efforts made by Dubai government to deliver sustainable investment and long-lasting legacy along with the planning for hosting of mega event of Dubai Expo 2020. Mega projects were planned and executed with consideration to meet the requirements of Event delivery for short period and lasting legacy to maximise the benefits from investment and address the demand of future development and growth of Dubai. For example, the infrastructure projects such as the planning of new route of metro line to connect Expo site with the city that was cost 11 bn AED was carefully studied and different alignment options were examined. The main drive of the selection process for new metro line that connects Expo site with Dubai railway network is to provide sustainable solution that serves existing major high-density communities besides Expo site. The approach adopted in selection process of the optimum alignment allows more consideration for transit oriented development TOD concept while planning for the route, in order to achieve the main objective, which is the continuity of service after the period of Dubai Expo 2020. Based on the evaluation score of four alignment options, alignment option 4 is the best option compared to other options 1, 2 and 3 for the following reasons:

- Meet project objectives and requirements and providing optimum travel time to the EXPO 2020 site
- Increase catchment area and Penetrates the dense area of the major existing developments and the proposed Stations could also serve future developments near Discovery Gardens and Al Furjan areas with potential for Transit Oriented Development (TOD) around the Stations
- Reduce the impact on existing and future roads/interchanges
- Reserve the future expandability of the line to serve and penetrate the heart of Al Maktoum Airport area
- Provide Integration of the new metro line system with other travel mode

Although the current study provides ground for benchmarking with Dubai model and present substantial amount of information that can help other cities in planning for hosting of future mega events, it is recommended that further research work is required to be carried out post event to measure the effectiveness of the plans and model adopted by Dubai and provide more data and information to present Dubai Expo 2020 as a model and benchmark for future hosting of mega events by other cities.

9 Acknowledgement

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Critical Success Factors towards Collaborative Road Infrastructure Projects Delivery in Tanzania

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Abstract
Infrastructure projects have been known for their importance to the economic development of a nation both during and after their delivery. However, achievement of infrastructure development goal, is reliant on how well their delivery is managed. Prevailing infrastructure projects delivery process in Tanzania has been experiencing inadequate collaboration among project participants. As a result, delivered infrastructure have been characterized by cost and time overrun, low quality and productivity, safety concerns and conflicts consequences. Establishing collaborative success factors in infrastructure delivery could improve the value of infrastructure facility as well as enhance their contribution towards economic development. The objective of the study was to establish critical success factors towards improved collaborative relationship in the delivery of infrastructure projects. Literature review on generic factors for successful collaboration relationship in project delivery process was conducted to collect secondary data. A structured questionnaire was used to collect primary data in order to establish stakeholders' perception on critical success factors for creating and maintaining collaborative relationships during infrastructure project delivery. Respondents targeted for the study were public clients (local government councils) which were represented country wide by council engineers; and consultants and contractors based in Dar es Salaam. Commitment, effective communication, efficient coordination, prompt problem solving and mutual trust were regarded to be the most important factors for collaborative relationship in infrastructure delivery project in Tanzania. Further, this study recommends that it is important to device and adhere to proper means of communication, coordination and problem solving in delivering roads infrastructure projects.

Keywords
Critical success factors, Collaboration and Infrastructure Project delivery.

1 Introduction

Economic development of a country is dependent on infrastructure facilities the country maintains (Arimah, 2017; Zhang & Ji, 2018; Yang, Huang, Huang, & Chen, 2020). Infrastructure is known for its role towards gearing development through facilitating movement of people and goods. In view of the above, countries seeking growth and development, must embrace effective and functional infrastructure facilities, as poor performance of infrastructure has a lot of implications to the well-being of the community and the country's economy as a whole (Arimah, 2017). Poorly delivered infrastructure's effect is more easily felts in cities and urban areas due to impaired mobility. Improved infrastructure can deliver major benefits capable of achieving Sustainable Development Goal (SDG) to make cities and human settlements inclusive, safe, resilient and sustainable (Arimah, 2017).

Arimah (2017) further states that economic growth and hence prosperity of African cities will depend on the extent to which infrastructure is adequately delivered, upgraded and maintained.

Despite the significance of the road infrastructure facilities to the economy, poor performance of their delivery has been a persistent challenge in many developing countries including Tanzania. Studies conducted in developing countries, (Banobi & Jung, 2019; Jongo, Tesha, Kasonga, Teyanga, & Lyimo, 2019; Mhando, Mlinga, & Alinaitwe, 2018; Sambasivan, Deepak, Salim, & Ponniah, 2017; Raphael & Phillip, 2016; Nyangwara & Datche, 2015; Kikwasi, 2013; Ramanathan, Narayanan, & Idrus, 2012; Eriksson and Westerberg, 2011) have revealed that infractucture and construction projects in general are characterised by poor performance at all stages of their development. As a result they impose severe constraints on economic development since the required infrastructure are either not made available or escalate their delivery and maintenance costs due to poor quality (Eriksson and Westerberg, 2011; Chen, Merrett, Lu, & Mortis, 2019).

Road infrastructure construction projects are very complex and involve high-risk (Chen, Merrett, Lu, & Mortis, 2019; Bennett & Peace, 2006). The uniqueness of products, the separation between design and construction in the traditional delivery system are among the root causes of the problems of poor performance in the construction industry (Naoum, 2003; Phua & Rowlinson, 2004; Eriksson & Laan, 2007). Construction undertaking being of project nature, are characterized by non-routine activities which have a high potential for misunderstanding arising from confusion over conflicting and multiple interpretations of causation that may affect their performance (Nikas & Argyropoulou, 2014). The limitations of the traditional delivery system adopted by the public bodies, the competitiveness and the perception of risks, lead to adversarial relationships among teams and hence impeding delivery of projects. Chen & Chen, (2007) states that problems in project teams have been caused by divergent objectives, motivations and perspectives held by team members. In the traditional procurement method, project performance depends on the supervision and inspection of the client representatives (Kashiwagi, Sullivan, Greenwood, Kovell, & Egbu, 2005). The lowest evaluated bid award system is applied based on the assumption that, first project plans and designs are complete, perfect and unambigous in terms of constructability; and secondly, that, given the first assumption, all that is remaining is to engage a contractor to carryout the works for the least amount of money under the supervision and inspection of the client or client representative. Contrary to these assumptions, most of the time plans and designs are not error free and therefore require regular reviews after construction commences (Chen, Merrett, Lu, & Mortis, 2019; Kadefors, 2004). In order to facilitate prompt and efficient review of these documents, all construction participants are to be involved and work together to enable successful delivery of projects, hence the need of collaboration

In the Tanzania, cost and time overrun and poor quality, environmental, health, safety performances and confrontational relationship among participants of the project are among the prevailing challenges in project delivery (Raphael & Phillip, 2016; Sambasivan et al., 2017; Mhando et al., 2018; Kalamata, 2018). Lack of sense of cooperation among the project teams fuelled by dissimilar objectives, competition and risks in the traditional delivery system has been identified to partly impede successful project delivery. Collaborative decision making could help improve infrastructure delivery and hence performance through shared expertise and experience amongst project parties. (Chen & Chen, 2007; Chen, Merrett, Lu, & Mortis, 2019) It is believed that collaborative working relationships in the delivery of road infrastructure will create a working environment that will facilitate achievement of overall project goals (Chen, Merrett, Lu, & Mortis, 2019; Bresnen and Marshall, 2002; Cooke-Davies, 2002; Phua & Rowlinson, 2004; Akintoye & Main, 2007).

This study has proposed collaborative working relationship within the traditional delivery system to improve project performance. However, critical success factors to harness available opportunities for collaboration in the traditional project delivery system in Tanzania, have not been well established.

With the existing gap on how to harness the available opportunities of collaborative working relationships in the traditional delivery system in mind, this research intends to establish the critical success factors for working collaboration amongst the project team members towards improved road infrastructure projects delivery in Tanzania.

This section has presented the introduction of the paper, where the background, problem statement and the research gap have been established. It is followed by a literature review in section two. In the third section, the methodology of the study has been covered. Research findings and discussion, has been presented in section four, while conclusion and direction for further studies, have been covered in section five.

2 Literature Review

Collaboration in project delivery can bring many advantages including risk sharing, cooperative problem solving, and increasing competitive advantages, as well as improved ability to deliver the project to the customers' requirements. (Chen, Merrett, Lu, & Mortis, 2019) Collaborative working in the delivery of infrastructure project can be considered as a strategy that can be applied to different forms of contract models rather than being viewed as an alternative contract form. (Chen, Merrett, Lu, & Mortis, 2019) Essentially, collaboration among different parties via a mutually developed, formal strategy of commitment and communication is focused on achieving "win-win" results for different project participants. (Chen & Chen, 2007) Successful project collaboration is based on multiple management and organizational factors, and determining which factors have the greatest influence over project success or failure. Establishing which critical success factors (CSFs) have the greatest influence requires detailed analysis of multiple factors of varying influence from experience and knowledge acquired from previous construction projects.

Studies on collaboration in construction projects have been the subject of concern over the past five decades. (Nikas & Argyropoulou, 2014; Chen, Merrett, Lu, & Mortis, 2019) Within this period, researchers have embarked on establishing success factors towards collaborative working in the delivery of projects. Despite the fact that the subject area has been very popular, there is still a need to remind ourselves as to what exactly is entailed by project success factors. Cooke-Davies, (2002), state the distinction between success criteria which are the measures by which success or failure of a project is judged, and success factors as those inputs to the management system that lead directly or indirectly to the success of the project. Project success factors, therefore are those attributes which when known and followed by project participants, can lead to successful project delivery. Having this definition in mind, critical success factors (CSFs), are therefore the most important factors among many that are more likely to positively affect performance of a construction project than others. Many studies have been conducted to investigating different aspects of critical success factors (CSFs) for projects using a wide range of methodologies. (Chen, Merrett, Lu, & Mortis, 2019)

Cooke-Davies, (2002) examined success factors for projects based on analysis of multinational firms respondents. The focus was on answering three key questions: "what factors lead to project management success", "what factors lead to a successful project", and "what factors lead to consistently successful projects." The study identified 12 factors which in one way or another are critical to successful project outcomes. Chen & Chen, (2007) identify, rank and clustered critical success factors for construction partnering in Taiwan using factor analysis approach. Gudiene, Banaitis, Podvezko, & Banaitiene, (2014) applied the Analytic Hierarchy Process (AHP) to identify and rank the relative importance of 10 CSFs from data collected from selected construction projects in Lithuania. In the findings, it was clear that having realistic project goals and project planning have the greatest influence over project success. Jelodar, Yiu, & Wilkinson, (2016) identify and conceptualise the possible attributes associated with relationship quality attributes in construction projects and explain how these qualities could be maintained and developed in construction procurement practices. In their study, they conducted an extensive literature review to establish the relationship quality attributes.

The fact that infrastructure construction projects are complex and that they engage many different players, call for a strong collaboration relationships among the participants for successful delivery. Despite this requirement, there have been very few studies on collaboration critical success factors in the infrastructure project delivery in the African continent south of the Sahara as a whole and Tanzania in particular. Several researches undertaken in Tanzania, though not dealt with directly, but have indicated the need for collaboration relationships among project participants in delivering projects. In his study, Kalamata, 2018, identifies delay in handling mismatches between project plans and actual site conditions to be among the causes of cost overruns for the donor funded projects in Tanzania. The delay in dealing with the discrepancies of dissimilarities between plans and site situations, could be attributed to inadequate sense of collaboration among the project team members.

In the study to analyse projects delays in Tanzania construction industry, Sambasivan et al., (2017), have linked escalation of transaction costs to project delays. They further asserted that the rise of transaction costs which is facilitated by the nature of coalitions among different parties with diverse economy and social perception, leads to among others, disputes in construction project delivery. This study therefore, articulate the need for a strong collaboration among participants in project delivery to avoid disputes that may arise due to hiking of project transaction costs. Again here, there is an indication towards stating that, disputes arising in project delivery are efficiently handled where there is collaborative working relationship among project team members. Mhando et al., (2018) developed a proactive mitigation model to reduce detrimental variations in construction projects. In the study, it has been established that, thorough involvement of project stakeholders and precise contract management practice formed the key features among the five features of the model developed. These features of the proposed model, could be facilitated and enhanced by a collaborative working relationship in delivering projects. Raphael & Phillip (2016), in their study to assess the critical factors that affect project quality performance in project financed by the government, state that, project collectivism that is built by commitment of project stakeholders, is key towards project success. In other words, the authors assert that collaboration working relationship is important towards successful project delivery in the tradition delivery system.

Though the above studies recognize the importance and need of collaborative working relationships in public infrastructure project delivery in Tanzania, but they have not harnessed the possibility of improving project performance through collaborative working relationships. Studies to establish collaboration critical success factors are essential towards improvements on infrastructure projects delivery. This study took an iniative towards filling the gap so as to open opportunities for further research. To achieve the goal of this study, a review of literature related to working collaboration success factors from past researches was performed. A number of success factors were established, and factors that were common among different studies, were considered for this study. Table 1 below presents 19 identified factors of collaboration in project delivery.

Table 1. Factors of collaboration working in project delivery

Author(s)	Factors
Black, Akintoye, and Fitzgerald, (2000); Cheng, Li, and Love, (2000); Cheng and Li, (2002); Chen, Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Naoum, (2003); Tang et al., (2006); Chan et al., (2004)	Mutual trust
Black, Akintoye, and Fitzgerald, (2000); Cheng, Li, and Love, (2000); Cheng and Li, (2002); Chen, Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Chen and Chen, (2007); Tang et al., (2006); Chan et al., (2004)	effective communication
Black, Akintoye, and Fitzgerald, (2000); Cheng, Li, and Love, (2000); Cheng and Li,	commitment from

(2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Chan et al., (2004)	senior management
Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	clear definition of responsibilities
[Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Chen and Chen, (2007); Akintoye and Main, (2007); Naoum, (2003)	acting consistence with objectives
Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	dedicated team
Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	flexibility to change
Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Chen and Chen, (2007)];	commitment to quality
Tang et al., (2006)	prompt problem solving
Cheng and Li, (2002); Naoum, (2003); Chan et al., (2004)	joint problem solving
Black, Akintoye, and Fitzgerald, (2000); Cheng, Li, and Love, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Chan et al., (2004)	long term perspective
Black, Akintoye, and Fitzgerald, (2000); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	total cost perspective
Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	formation at design stage
Black, Akintoye, and Fitzgerald, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	good cultural fit
Black, Akintoye, and Fitzgerald, (2000); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010)	financial security
Black, Akintoye, and Fitzgerald, (2000); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Tang et al., (2006)	commitment to win-win attitude
Black, Akintoye, and Fitzgerald, (2000); Cheng, Li, and Love, (2000); Cheng and Li, (2002); Huang, Lin, and Mortis, (2008); Chen and Kao, (2010); Akintoye and Main, (2007); Chan et al., (2004)	availability of resources
Black, Akintoye, and Fitzgerald, (2000); Akintoye and Main, (2007); Huang, Lin, and Mortis, (2008); Tang et al., (2006)	fair treatment
Cheng, Li, and Love, (2000); Cheng and Li, (2002); Chan et al., (2004)	efficient coordination

This section has defined and shown the distinction between success criteria and success factors. It has also depicted the importance of success factors in delivering infrastructure projects. The section has finally identified factors for collaboration in delivering infrastructure projects. The following section describes the methodology adopted in order to achieve the objective of the study.

3 Research Methodology

3.1 Research Design

The objective of the study was to establish critical success factors for collaborative working relationships in infrastructure project delivery in Tanzania. Using a quantitative research approach, data was collected through a questionnaire survey. 19 factors established through literature review were tabulated in a questionnaire form. The questionnaire was divided into two main parts which covered for all; client, consultants, and contractors; Part I of the questionnaire enquired general information of respondents. These included among others, experience in the construction industry, education qualification and category of registration in case of contractors. Part II included the list of the factors identified from a literature, in which respondents were asked to rate the degree of criticality of each factors using a 5-point Likert scale. The ratings used to determine the degree of participants' perceived contribution of each factor towards establishing collaboration working relationship (criticality) were; strongly agree = 5, Agree = 4, Neutral= 3, Disagree = 2, strongly disagree = 1. Factors that received high ratings with apparent and relative ranking agreement among all stakeholders (clients, consultants and contractors) participated in the study, were considered to be important in establishing working collaboration. Hence, they were regarded as critical success factors towards collaborative infrastructure project delivery.

3.2 Population and Sample of the Study

The study population consists of construction industry stakeholders including mainly, clients (local councils' engineers), consultants and contractors. Public clients were chosen over private ones since they are the major owners and financiers of public road infrastructure. In addition, all public bodies are required by the procurement legislation to use defined procurement methods. Although, a few consultants and contractors (50 from each) were involved in the research at the convenience of the researcher to validate the study, judgmental sampling was adopted to choose public clients as the main target over the other stakeholders. This was due to the fact that the researcher sees to it that public client is the prime mover towards most improvements efforts sought in the society. On the other hand, convenient sampling was used as collection of data was done from council engineers who were attending an annual conference organized by the Ministry of Infrastructure in which sixty six (66) council engineers were targeted. Giving questionnaires to individuals who were accessible and willing to participant in the study, also formed a convenient sampling technique.

3.3 Response profile

The proportion of the respondents comprised of 58% clients (local council employee), 62% consulting firms, and 68% contractors. Majority of respondents were engineers (94%) with bachelor's degree as their minimum educational qualification. With regard to the experience of respondents, it was established that the majority of respondents (77%) have work experience of more than 5 years in construction, of which, 27% have experience of more than 10 years. Majority of the contractors (85%) in the study were those registered to operate as contractors class four (IV) to six (VI) while the remaining portion (15%) were class one (I) contractors. Since the majority of the Contractors respondents are between class one and six, their responses can be considered credible for the study. Class of categorization of contractors participated in the study indicates they must have implemented a large number of high value projects and faced collaboration issues. Furthermore, experience of working in the construction industry and education qualification of respondents prove to give valid responses for the purpose of the study.

3.4 Data Analysis

Using a 5-point rating scale, the respondents were asked to give their opinion by rating the factors identified from the literature to show the degree of contribution (criticality) of the established factors towards forming collaboration relationships. In the analysis of the collected information, the computation of Relative Importance Index (RII) of each factor rated by the respondents was adopted. The weighted average rating of each factor was computed using equation 1 below.

$$\text{RII} = \sum_{i=1}^{5} \frac{w_i x_i}{5 * N} \qquad (1)$$

Where; *RII* = Relative Importance Index, w = weighting given to each factor, x = Score frequency of i^{th} response to each factor, N = number of respondents for a particular influence factor.

4 Findings and Discussion

The 19 factors contributing to project collaboration relationships were mapped in terms of criticality represented by the Relative Importance Index (RII) as described in the previous section. The results of a questionnaire survey are presented in Table 2 below. From the analysis of results, it has been established that, council engineers regard clear definition of responsibilities (RII=0.874) to be the most critical success factors for collaboration working relationship. Commitment to quality (RII=0.870) has been regarded as the second most critical success factor. In addition to clear definition of responsibilities and commitment to quality; effective communication (RII=0.863), mutual trust and prompt problem solving (all with RII=0.858), were identified to make the top five most critical factors as rated by the clients group. On the other hand, good cultural fit was the lowest (RII=0.742) rated factor, indicating that, clients consider cultural issues to be of less importance in influencing collaboration among project participants.

Respondents from the consultants group perceive commitment to quality (RII=0.923) to be very critical towards forming collaborative working relationships. The second ranked factor by consultants in establishing collaboration among project teams, is effective communication (RII=0.890). Among the already mentioned factors, consultants' top five list of factors towards successful working collaboration relationships, includes joint problem solving (RII=0.884), efficient coordination (RII=0.871) and dedicated team (RII=0.865). Good cultural fit was the lowest rated (RII=0.755) factor by consultants, indicating that, consultants are in agreement with clients and consider cultural issues to be insignificant towards forming collaboration among project participants. The findings of the study indicates that contractors considered effective communication (RII=0.988) to be a very important factor in form collaborative working relationship. Effective communication, was followed by efficient coordination (RII=0.959) and commitment to quality (RII=0.953). Mutual trust and prompt problem solving, with relative importance indexes of 0.941 and 0.935 respectively, form the top five list of factors in establishing collaborative working relationships together with effective communication and efficient coordination. It was also noted from the results that, dedicated team (0.918), availability of resources (0.918), commitment to win-win attitude and fair treatment (both 0.906) and joint problem solving (0.900), were rated very high by contractors, indicating the importance of these factors towards forming collaborative working relationships in undertaking construction projects.

Table 2: Factors for Collaborative working relationships

Factors for success	**Council Engineers**		**Consultants**		**Contractors**	
	RII	**Ranking**	**RII**	**Ranking**	**RII**	**Ranking**
Mutual trust	0.858	4	0.839	12	0.941	4
Effective communication	0.863	3	0.890	2	0.988	1
Commitment from senior management	0.843	7	0.839	13	0.812	14
Clear definition of responsibilities	0.874	1	0.858	8	0.888	11
Acting consistence with objectives	0.827	9	0.839	14	0.888	12
Dedicated team	0.800	12	0.865	5	0.918	6
Flexibility to change	0.805	11	0.826	16	0.771	18
Commitment to quality	0.870	2	0.923	1	0.953	3
Prompt problem solving	0.858	5	0.858	9	0.935	5
Joint problem solving	0.842	8	0.884	3	0.900	10
Long term perspective	0.773	16	0.865	6	0.771	19
Total cost perspective	0.800	13	0.806	17	0.776	17
Formation at design stage	0.768	17	0.806	18	0.782	15
Good cultural fit	0.742	19	0.755	19	0.782	16
Financial security	0.768	18	0.852	10	0.871	13
Commitment to win-win attitude	0.800	14	0.845	11	0.906	8
Availability of resources	0.816	10	0.865	7	0.918	7
Fair treatment	0.800	15	0.839	15	0.906	9
Efficient coordination	0.847	6	0.871	4	0.959	2

Furthermore, from the results of the study, it has been indicated that there is a relative agreement among respondents that effective communication (ranked third by council engineers, second by consultants and first by contractors), commitment to quality (ranked second by council engineers, first by consultants and third by contractors) are very important factors towards collaborative working relationships. There is also a relative agreement on the importance of efficient coordination towards creating collaborative working relationships in delivering infrastructure projects between consultants (ranked 4th) and contractors (ranked 2nd). The agreement among the parties on the relative ranking of the factors towards their contribution to collaborative working, can be interpreted that respondents to the study regard effective communication and efficient coordination to be important factors towards achieving project quality as one of major metric for project success. It can therefore be deduced from the findings of the study that respondents believe that attaining quality and other project goals depend very much on the proper project communication and coordination among the project parties as depicted by researches undertaken previously (Erikson and Laan, 2007; Papadopoulos & Pantouvakis, 2010; Strickland, 2010).

In addition, by rating very high mutual trust (0.941), contractors are of the opinion that mutual trust among project stakeholders forms a significant ingredient towards successful project team collaboration. This indicates that contractors believe that trust, if built within the project team, can enhance communication among project participants as well as facilitating contractors' self-performance control during project activities execution. It means that contractors have the opinion that the current project-operating situation to be dictated by owners through consultants in which contractors have to follow and comply with instructions is not doing well to the construction industry (Strickland, 2010).

Contractors also consider that prompt solving of construction problems (0.935) is a very important factor towards establishing project team collaboration. It should be noted that problems in undertaking construction projects are inescapable, therefore prompt and joint solutions are vital to increase trust and building dedicated teams (Erikson and Laan, 2007; Strickland, 2010). Generally, the results of the study show that contractors seem to have rated the collaboration success factors very highly. The interpretation of their high ratings could be that they are the ones who are more affected by the current delivery system and hence are in favour of collaboration working relationships direction. On the other hand, consultants and contractors respondents relatively concurred in their opinion by ranking equally availability of resources (7th ranked by each). Though the ranking was the same by each party, however, contractors rated this factors very highly (0.918) indicating the way they perceive the important availability of resources towards collaborative relationships and therefore project success. (Jelodar et al., 2016; Cheng, Li, & Love, 2000; Chan et al., 2004)

5 Conclusions and Further Research

The objective of the study was to establish critical success factors for collaborative working relationships towards improved road infrastructure projects delivery and performance. The findings of the study indicate that there are quite a number of critical success factors that can facilitate collaborative working relationship in delivering road infrastructure projects in Tanzania. In analyzing criticality index for the 19 established factors for collaborative working relationship, it was observed that effective communication and commitment to quality are the top most critical factors. These two factors together with efficient coodination, prompt problem solving and mutual trust, made the list of the top five criticl success factors for collaboration working relationships in delivering roads infrastructure projects in Tanzania. This implies that if these factors are considered, may facilitate collaborative working relationships and hence help improve the delivery and performance of road infrastructure construction projects.

The study recommends that it is important to device and adhere to proper means of communication, coordination and problem solving in delivering roads infrastructure projects. Effective communication and coordination among project parties at great extent could assist in road infrastructure projects performance improvement. If parties to projects will coordinate and convey information to each other quickly, will avoid problems in delivering projects and also improve mutual trust among them. This study made an attempt to contribute to the literature on collaboration relationship in delivering infrastructure projects in Tanzania. It therefore paves a way for further research on working collaboration in order to improve performance of infrastructure project delivery. Among others, further research is recommended on the relationship among the factors. Establishment of relationships among factors of collaboration success, will help to identify interdependences that exist among the factors.

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Terrestrial Laser Scanner analytical modelling towards effective scan area planning for damage detection on structural members

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Abstract
Non-contact measurement technology such as Terrestrial Laser Scanning (TLS) can detect damages on the surface profile of structural members such as bridge components quickly and reliably compared to traditional diagnostic methods. However, the accuracy of the point clouds collected using the TLS depends on various factors such as atmospheric conditions, scanning surface properties, scanner angular resolution, and its location. Among all the influencing factors, the location of the scanner from the target surface is the only operator-controlled factor. Further, it has a significant influence on the interpoint spacing of point clouds, which affects the accuracy. Therefore, an appropriate selection of scanner location beforehand helps to accurately collect the point cloud data. In this research, a set of mathematical equations are proposed using trigonometric relationships to understand the variation of interpoint spacing when the scanner location varies on structural components. The calculated interpoint spacing values using the proposed equations are validated through a known field scan experimental result. A set of interaction graphs are obtained using the proposed equations, and its analytical calculations on various scanning locations are helpful in deciding TLS coverage areas while measuring the damages on structural components with differing accuracy. Further, the study demonstrated the procedure to obtain the customizable scanning accuracy by fixing the various TLS data acquisition parameters.

Keywords
Inter point spacing, Structural inspection, Terrestrial laser scanning

1 Background of the study

Damages due to environmental and human factors are inevitable to any structural component that causes distress to the whole structural system. According to a report by Indian Bridge Management System (IBMS), more than 137 bridges were classified as distressed, which emphasizes the importance of timely maintenance and early damage detection intervention to extend the life and serviceability of the structural system (De Belie and Gruyaert 2016).

Traditionally, periodic monitoring of the bridge structural members is done by employing conventional diagnostic methods in which inspectors visit the site periodically and perform visual inspections. After the inspector's evaluation and based on his subjective assessment of the quantum of damages, various Non-destructive tests (NDT) such as the ultrasonic pulse velocity test, rebound hammer test, penetration method, and many other tests are performed (Niederleithinger *et al.* 2020). Despite high accuracy, these methods require the deployment of costly special types of equipment, such as an 'under-bridge truck' to access the assessment area. Due to this reason, countries like in India, the assessment is performed only at the critically damaged areas instead of periodic proactive and exhaustive manner. In addition, it is a great challenge to inspect damages of the same area over a period as there used to be no preceding accurate data to compare with instead of the subjective assessment statements by the experts. Besides, these methods also require an assessment area to be accessible every time. Therefore, employing non-contact proactive monitoring methods can overcome the limitations associated with these traditional inspection-based assessments and monitoring (Thomas *et al.* 2013; Abdo 2014).

Evidently, Digital imaging and Three-dimensional (3D) laser scanning or otherwise LiDAR are considered as most effective non-contact measurement technologies for rapid and precise detection of preliminary structure damages. In both Photogrammetry and LiDAR, the structure is captured as 3D point cloud data, which are generally defined in a cartesian coordinate system (X, Y, and Z) along with RGB colour values. Image-based acquisition of 3D point clouds using robotic equipment such as UAVs/drones have created vast new prospects for the rapid and detailed 3D point cloud generation. These point cloud data are then utilized for structural damage detection through Multiview-Stereo (MVS) and Structure-from-Motion (SfM) and other Photogrammetry based algorithms (Ullman 1979; Alfonso-Torreño *et al.* 2019; Giordan *et al.* 2018). However, in the case of photogrammetry, for large-scale structures such as bridges, the image quality is influenced by many factors such as the surrounding environmental conditions, distortion, etc., and it is time-consuming (Walter *et al.* 2018). But the deployment of 3D laser scanning technology shows advantages in terms of processing time and quality. It covers a whole $360^{\circ} \times 310^{\circ}$ field of view (FOV) and generates dense point cloud data (Chen 2012).

LiDAR technology is widely applied to monitor large-scale non-moving structures such as bridges, tunnels, etc, on a temporal basis (Riveiro *et al.* 2016). It collects data over time to detect structural changes due to events like seasonal variations, accidental impact, natural calamities such as earthquakes, landslides, heavy rain, etc. Further, the laser scanner units are primarily classified based on its data capturing modes, such as aerial, mobile, and terrestrial. Aerial scanners refer to laser scanning corresponding to air (e.g., helicopter, plane, or drone), mobile equipment is based on LIDAR mounting on moving vehicles (e.g., car, van, train, or boat), and terrestrial are the scanners located at a static position on to the ground and collect data. Although each of these LIDAR data collection methods has its own advantages and limitations, the TLS is more common and widely adopted in static condition monitoring to detect the temporal variations of the structures and its components such as cracks and deformations (Liu *et al.* 2010). Detection of the structural damages on a millimeter scale remains the most challenging task because it requires a higher number and closer points on surfaces to accurately detect the damages. The number of points on the unit area of surfaces is known as the density of point clouds. It depends on factors such as atmospheric conditions, object surface properties, scanning geometry, and instrument mechanism (Soudarissaname *et al.* 2009). Furthermore, the scanning geometry is influenced by the distance and orientation of the scanned surface with respect to the scanner position. Therefore, the position of the scanner decides the density of the point clouds. The main aim is to obtain a sufficiently dense point cloud to detect minor damages. There are several other factors that affect point cloud density, including characteristics of the scanner, scanning surface material, and so on, but these are outside the operator's control. A distance from the scanning surface is the only factor under the operator's control. In this regard, Laefer *et al.* (2014) developed a fundamental mathematical model to measure minimum detectable crack in unit-based masonry. In this study, laboratory experiments were performed to check the model's reliability. Some of the recommendations on TLS location and FOV are given to measure certain threshold dimension cracks. In another effort, Anil *et al.* (2013) conducted a lab experiment to evaluate the effect of scanner distance from the scanning surface to detect cracks on concrete frames with varying widths, orientations, and depths by using various types of scanners. In a related context, Cabo *et al.* (2017) proposed a way to find the best scanner position to scan heritage facades by considering various constraints such as distance between scanner and scanning surface, scanner resolution.

Previously, very few studies have been undertaken with limitations on the structural members other than complex and large structures, such as bridge structural components, to identify scan location and parameters for collecting sufficient point density data towards deducting the damages (Rashidi *et al.* 2020). Hence, the proposed study focuses on analysing the variation of point density with interpoint spacing that could facilitate effective scan location and coverage area with the desired tolerances scale on structural damage deduction. The paper is organized into 4 sections; the next section deals with the methodology, development and analysis of the mathematical model. The third section discusses the validation of the model and further section present summary and conclusion.

2 Methodology

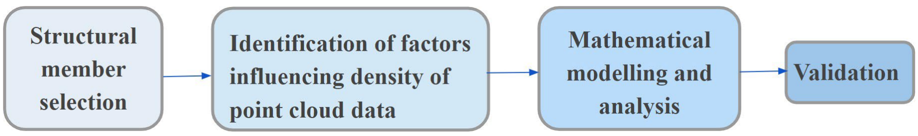


Figure 1. Broader outline methodology.

The above flow diagram shows the four sequential steps of the methodology proposed. This study focuses on the most common preliminary damage formation, structural members of components such as the rectangle piers, abutments, and wing walls with a vertical straight surface. The first step for the precise measurement of the damages on these components using TLS is to identify the factor that influences the density of point clouds. According to the literature review, the distance between the scanner and the scanning surface is the most important factor affecting the density of point clouds. The longer distance of the scanner from the target results in higher interpoint spacing and, thereby, lower density. Therefore, to collect the required spatial density, it is necessary to analyse the variation of point spacing by changing the distance of the scanner from the surface in a predefined manner. The following sub section describes the analysis and plotting of the interpoint space variation with distance on the aforementioned components using the basic mathematical formulation. Afterwards, the determined value of the interpoint spacing is validated using known field experiments, as detailed in section 3. The surveyor can use a plotted graph of the analyses to decide effective scan area from a selected TLS location with his desired accuracy level on the point cloud data, i.e., the interpoint spacing.

Analysis of point spacing variation on structural components

The scanning of structural components can be carried out typically into two planes from a specific position of the TLS. As shown in Figure 2, the first plane XZ is perpendicular to the scanning axis of TLS, whereas the second one, YZ, is parallel to the scanning axis of TLS. Thus, it is necessary to analyse the variations on both planes.

Case 1. Analysis of point spacing variation on the plane perpendicular to the scanning axis of TLS (XZ)

TLS scans the XZ plane by locating millions of points in vertical parallel lines. It will first rotate by angle $\Delta\emptyset$ along a length (L_X), then it will rotate no of times along length (L_Z) by an incremental angle of Δθ. The distance covered by rotating the angles ΔØ and Δθ is known as interpoint spacing which is denoted by a_h and a_v (see in Figure 3). The interpoint spacing increases as the scanning lengths L_X and L_Z increase, as well as the variation, also depending on the scanner distances from the surface (D).

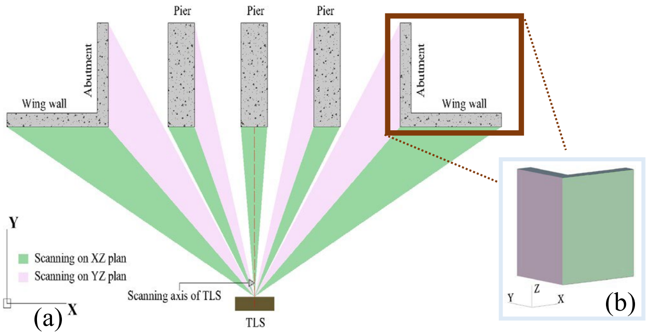


Figure 2. Scanning field of view of the bridge structural components covered from a particular location of TLS. (a) Top view (b) Isometric view of abutment and wing wall.

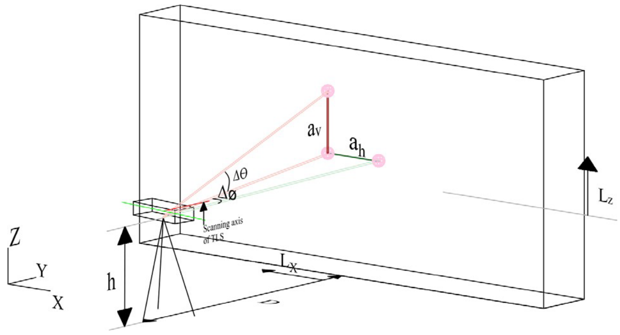


Figure 3. Scanning of a plan perpendicular to the scanning axis of TLS.

From Figure 3, using trigonometric relationships, the following equations can be derived.

$$L_{X'} = \left(\left(\tan \left(\tan^{-1}\left(\frac{L_X}{D} \right) + \Delta\varnothing \right) \right) \times D \right) \quad (1)$$

$$a_h = \left(L_{X'} - L_X \right) \quad (2)$$

$$R = \sqrt{(L_{X'})^2 + D^2} \quad (3)$$

$$a_v = \left(\left(\tan \left(\tan^{-1}\left(\frac{L_Z}{R} \right) + \Delta\theta \right) \right) \times R \right) - L_Z \quad (4)$$

The value of a_h and a_v can be calculated using the above equations (1 to 4). Following that, the detailed analysis of variations on interpoint spacing against various predefined distance D is carried out to plot the change in a_h and a_v value along respective L_X and L_Z lengths (see Figure 4 and Figure 5).

For example, in Figure 4, to get the accuracy of less than 2 mm in the X direction with the length of 5.4 m as L_X, the scanner can be located anywhere between 3 m to 10 m. Further, deducing the L_Z value, the surveyor could make out the area in which the scanner would be effective to get less than 2 mm accuracy through keeping its interpoint spacing as 2 mm.

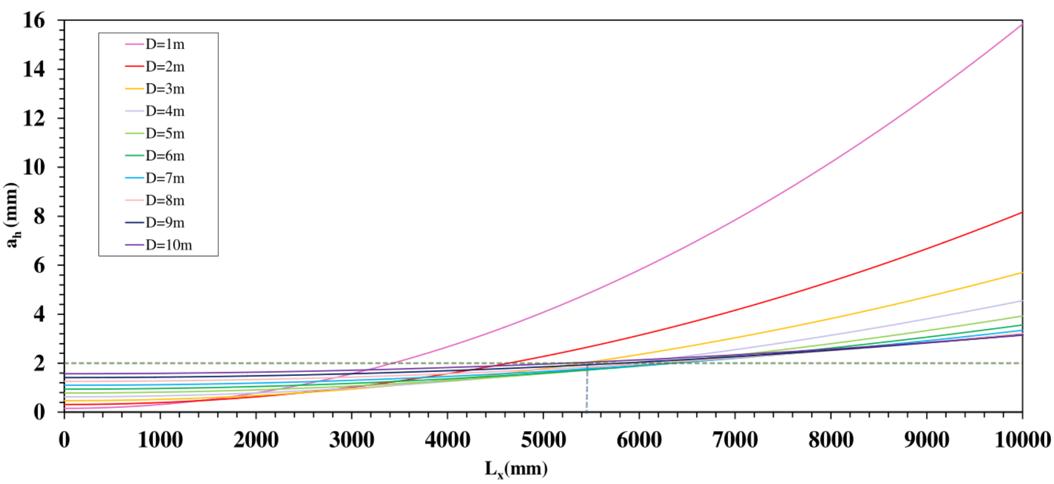


Figure 4. Variation of inter point spacing a_h along horizontal length (L_X) with different TLS distance (D) at 0.009^0 degree TLS incremental angle (ΔØ).

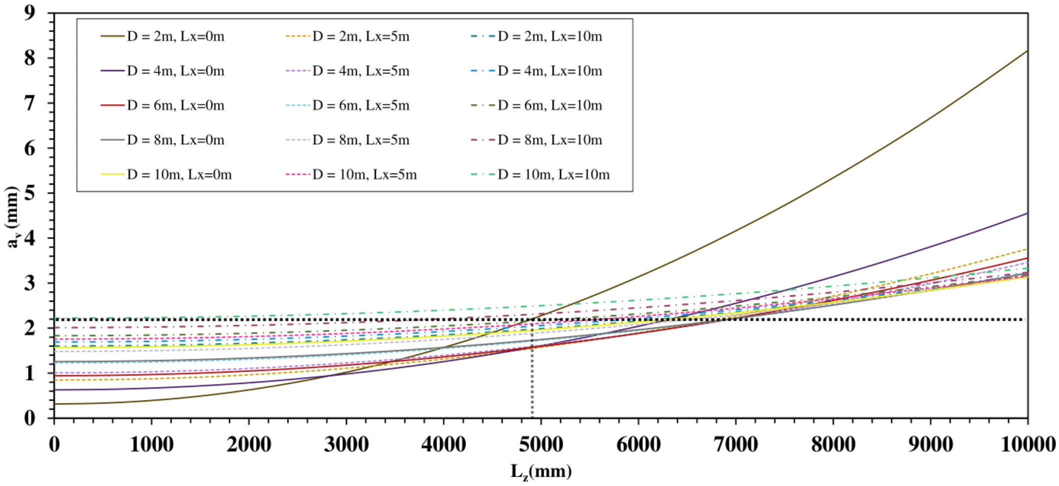


Figure 5. Variation of inter point spacing a_v along vertical length (L_Z) with different TLS distance (D) at 0.009^0 degree TLS incremental angle ($\Delta\theta$).

Previously, from Figure 4, the values of L_X and D have been decided to get an accuracy of less than 2 mm. Furthermore, in order to get the same level of accuracy in the Z direction, scanning needs to be done up to length of 4.9 m along this direction (see Figure 5). Thus, the surveyor can cover a scanning area of 5.4 m × 4.9 m ($L_X \times L_Z$) by placing TLS anywhere between 3 m to 10 m from the scanning surface.

Case 2. Analysis of point spacing variation on the plane parallel to the scanning axis of TLS (YZ)

As similar to case 1, the point spacing variation on the YZ plane depends upon the parameters such as scanning lengths L_Y and L_Z and scanner longitudinal distance from the extreme end of surface (D). Apart from that, it also depends upon the scanner lateral distance from the surface (B) (see in Figure 6).

From Figure 6, the following equations can be derived using trigonometric relationships.

$$D' = \left(\frac{B}{\tan\left(\tan^{-1}\left(\frac{B}{D-L_Y}\right)+\Delta\varnothing\right)} \right) \qquad (5)$$

$$a_h = \left(\left(D-L_Y\right)-D'\right) \qquad (6)$$

Equation 5 and 6 are valid up to $L_Y = D$

$$R=\sqrt{\left(D'\right)^2+B^2} \qquad (9)$$

$$a_v = \left(\left(\tan\left(\tan^{-1}\left(\frac{L_Z}{R}\right)+\Delta\theta\right)\right)\times R\right)-L_Z \qquad (10)$$

Equation 9 and 10 are valid up to $L_Y = D$

$$D'' = \left(\left(\tan\left(\tan^{-1}\left(\frac{L_Y-D}{B}\right)+\Delta\varnothing\right)\right)\times B\right) \qquad (7)$$

$$a_h = D''-L_Y+D \qquad (8)$$

Equation 7 and 8 are valid for $L_Y > D$

$$R=\sqrt{\left(D''\right)^2+B^2} \qquad (11)$$

$$a_v = \left(\left(\tan\left(\tan^{-1}\left(\frac{L_Z}{R}\right)+\Delta\theta\right)\right)\times R\right)-L_Z \qquad (12)$$

Equation 11 and 12 are valid for $L_Y > D$

The above equations (5 to 12) can be used to calculate the values of a_h and a_v. Following that, the same procedure as in case 1, is used in order to plot the variations in a_h and a_v value along respective L_Y and L_Z lengths (see Figure 7 and Figure 8).

For example, suppose the surveyor wants to achieve approximately 2 mm interpoint spacing on this plan as well. In that case, TLS should be placed at a longitudinal distance (D) of least 4 meters and lateral distance (B) of least 5 meters from the scanning surface, and 5.3 m × 4 m (LL_{YY} × L_{ZZ}) scanning area will be covered (see Figure 7 and Figure 8).

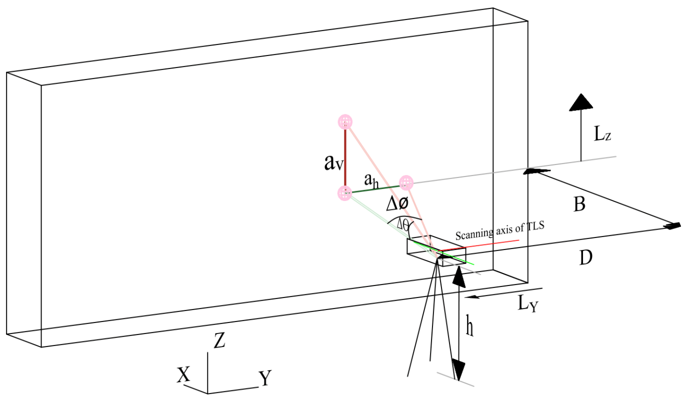


Figure 6. Scanning of plan parallel to the scanning axis of TLS.

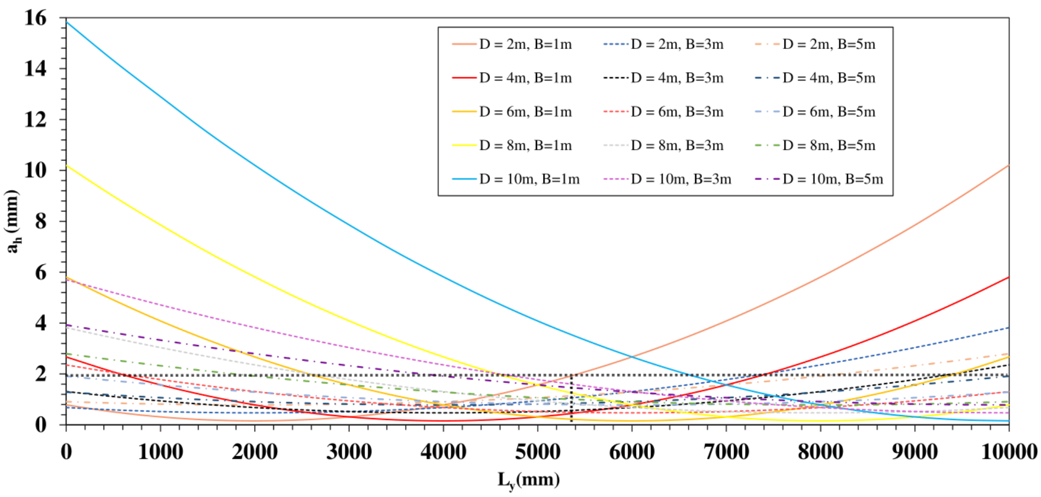
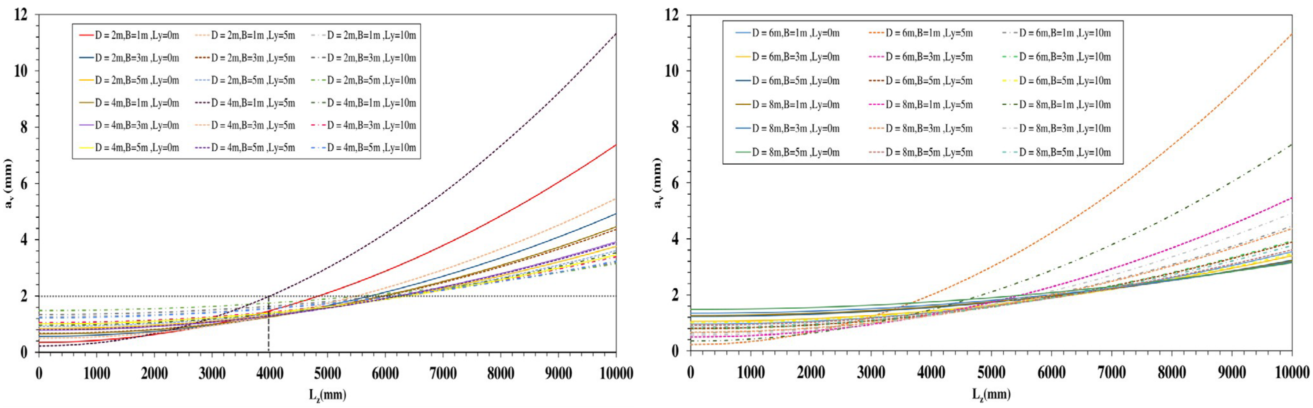


Figure 7. Variation of inter point spacing a_h along horizontal length (L_Y) with different combination of longitudinal and lateral TLS distance (D and B) at 0.009^0 degree TLS incremental angle (ΔØ).



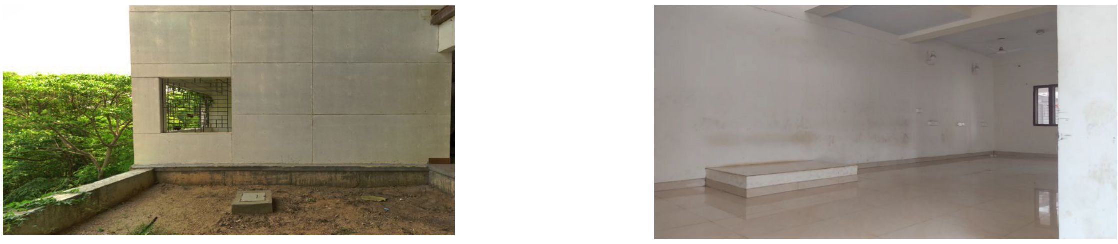
(a) (b)

Figure 8. Variation of point spacing a_v along vertical length (L_Z) with different combination of longitudinal and lateral TLS distance (D and B) at 0.009^0 degree TLS incremental angle (Δθ). (a) This graph is applicable up to 4 m TLS distance and Graph (b) This graph is applicable up to 8 m TLS distance.

3 Validation

3.1 Data collection

The locations chosen to perform the experiments for verification of interpoint spacing value on a plane perpendicular and parallel to scanning axis of TLS are vertical straight grid wall (see Figure 9(a)) and multi-purpose hall (see Figure 9(b)). The reason behind choosing these locations was that there was enough room available to scan the surface by moving the scanner to a longer distance.



(a) (b)

Figure 9. The locations for verification of interpoint spacing value (a) vertical straight grid wall (b) multi-purpose hall.

The data for the experiment was collected using a TLS with a horizontal and vertical angle increment of 0.009^0. The specifications of TLS include, range 0.6 to 350 m, Field of view (vertical /horizontal): 300° / 360°, Min angular increment (vertical/horizontal): 0.009° / 0.009°, Laser wavelength: 1550 nm and Measurement speed (pts/sec): 976,000

3.2 Verification of interpoint spacing value on a plane perpendicular to the scanning axis of TLS

Actual interpoint spacing a_h and a_v of point clouds were measured using processing software at multiple sections of surfaces. Figure 10 and Figure 11 illustrate the measured value of a_h and a_v, respectively, at intersection points of two sections (i.e., A, B, etc.). The section was taken along the horizontal length (L_X) of 233.1 mm, 1032.3 mm, 2128.8 mm and 1596.8 mm, as well as along vertical length (L_Z) of 1306.5 mm, 0 mm and 1084.2 mm, and the scanner was placed at 4 m from the surface.

Table 1 and Table 2 below represents the calculated interpoint spacing value and above measured value and their comparison. It can be noticed that the maximum difference between calculated and measured values are 0.1 mm, which is extremely negligible and also due to atmospheric effects, surface unevenness, etc.

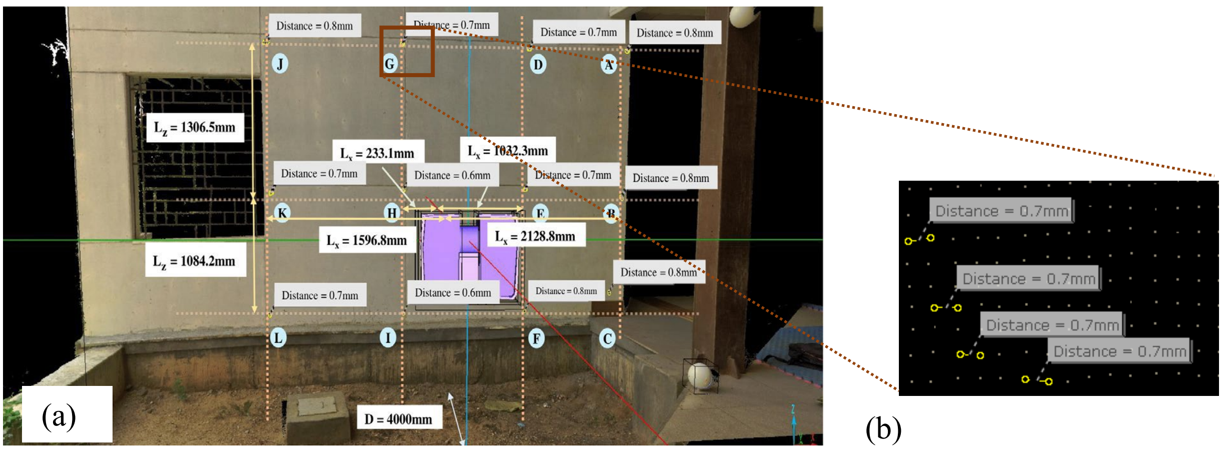


Figure 10. (a) Measurement of point cloud interpoint spacing a_h, at intersection points of sections along lengths L_X and L_Z (b) a_h measured at intersection point G.

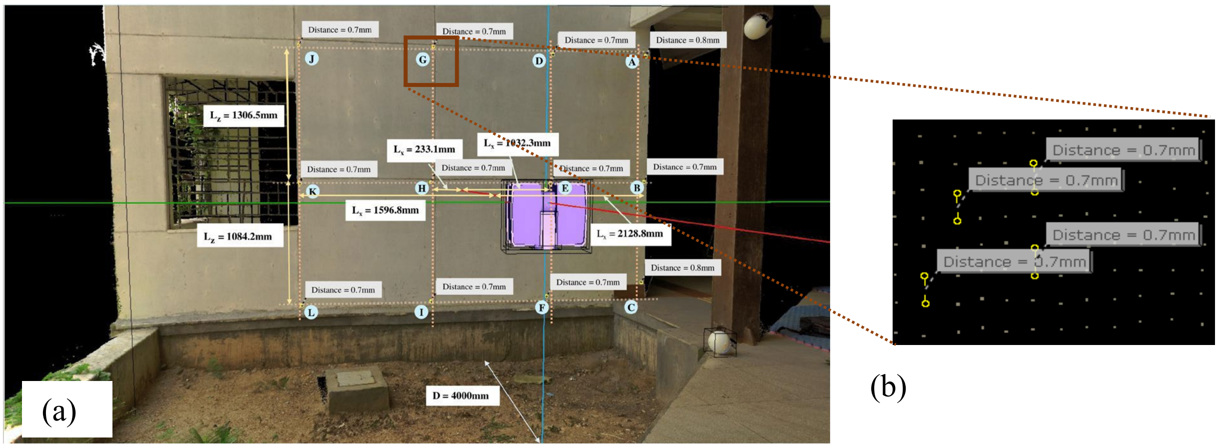


Figure 11. (a) Measurement of point cloud interpoint spacing a_v, at intersection points of sections along lengths L_X and L_Z (b) a_v measured at intersection point G.

Table 1. Comparison of calculated and actual horizontal interpoint spacing a_h at different intersection point of the sections.

S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f
A	0.8	0.8063	-0.0063	D	0.7	0.6701	0.0299	G	0.7	0.6305	0.0695
B	0.8	0.8063	-0.0063	E	0.7	0.6701	0.0299	H	0.6	0.6305	-0.0305
C	0.8	0.8063	-0.0063	F	0.8	0.6701	0.1299	I	0.6	0.6305	-0.0305

Note:
1. S_N, M_v, C_v and D_f represents name of intersection point, measured value, calculated value and difference respectively
2. All values are in mm

Table 2. Comparison of calculated and actual vertical interpoint spacing a_v at different intersection point of the sections.

S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f
A	0.8	0.7710	0.0290	D	0.7	0.7138	-0.0138	G	0.7	0.6963	0.0037
B	0.7	0.7118	-0.0118	E	0.7	0.6489	0.0511	H	0.7	0.6294	0.0706
C	0.8	0.7526	0.0474	F	0.7	0.6936	0.0064	I	0.7	0.6755	0.0245

Note:
1. S_N, M_v, C_v and D_f represents name of intersection point, measured value, calculated value and difference respectively
2. All values are in mm

3.3 Verification of interpoint spacing value on a plane parallel to the scanning axis of TLS

The interpoint spacing value, a_h and a_v of point clouds on this surface were measured in the same manner as followed in section 3.2. Here, the section was taken from the extreme edge of the surface on a horizontal length (L_Y) of 0 mm, 4744.9 mm, 9489.8 mm as well as along vertical length (L_Z) of 1373.7 mm, 0 mm and 1161.6 mm, and the TLS placed at 4744.9 mm longitudinal distance(D) and 3132.6 mm lateral distance (B) (see in Figure 12 and Figure 13).

Following that, a comparison of the calculated interpoint spacings value and above measured value has been carried out (Table 3 and Table 4). Here also, the maximum difference between calculated and measured values was noticed only 0.1 mm.

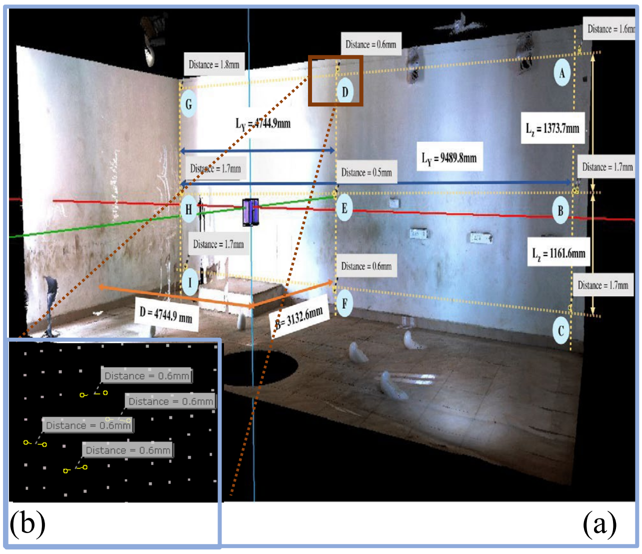


Figure 12. (a) Measurement of point cloud interpoint spacing a_h, at intersection points of sections along length L_Y and L_Z (b) a_h measured at intersection point D.

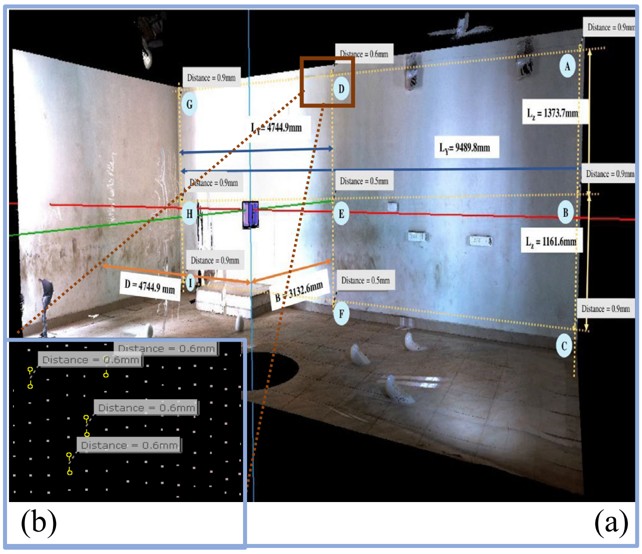


Figure 13. (a) Measurement of point cloud interpoint spacing a_v, at intersection points of sections along lengths L_Y and L_Z (b) a_v measured at intersection point D.

Table 3 Comparison of calculated and actual horizontal interpoint spacing a_h at different intersection point of the sections.

S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f
A	1.6	1.6213	-0.0213	D	0.6	0.4921	0.1079	G	1.8	1.6206	0.1794
B	1.7	1.6213	0.0787	E	0.5	0.4921	0.0079	H	1.7	1.6206	0.0794
C	1.7	1.6213	0.0787	F	0.6	0.4921	0.1079	I	1.7	1.6206	0.0794

Note:
1. S_N, M_v, C_v and D_f represents name of intersection point, measured value, calculated value and difference respectively
2. All values are in mm

Table 4. Comparison of calculated and actual vertical interpoint spacing a_v at different intersection point of the sections.

S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f	S_N	M_v	C_v	D_f
A	0.9	0.9454	0.0454	D	0.6	0.5867	0.0133	G	0.9	0.9450	0.0450
B	0.9	0.8933	0.0067	E	0.5	0.4921	0.0079	H	0.9	0.8929	0.0071
C	0.9	0.9306	0.0306	F	0.5	0.5597	0.0597	I	0.9	0.9302	0.0302

Note:
1. S_N, M_v, C_v and D_f represents name of intersection point, measured value, calculated value and difference respectively
2. All values are in mm

4 Summary and Conclusions

This study shows that the terrestrial laser scanner can be used as one of the accurate and non-contact 3D data acquisition technologies to measure the structural component damages. Its accuracy could be customized by fixing the various TLS data acquisition parameters. This study proposed an analytical solution to the point spacing variation on structural components by varying the TLS data acquisition parameters. The determined point spacing value is verified using field scan experiment results. Using the proposed analytical point spacing variation graph, the user can decide the standardised data acquisition parameters such as the distance between the target and the scanner, the effective scan area coverage from selected TLS locations, the angular increment etc. The accuracy of the scanning data could be customizable based on the need of the user and the nature of the investigation on structural component damages such as deformation tolerance, crack width etc. The study can be extended in future to analyse point spacing variation on the circular cross-sections and the specific purpose structural components and damage assessment.

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Assessment of the Variation in the Maintenance of HVAC Component Units and Its Energy Consumption Implication

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Abstract
The proper maintenance of the Heating Ventilation and Air Conditioning (HVAC) system promises various advantages ranging from energy savings, decreasing maintenance costs, prevention of hazardous conditions, increase the service life of HVAC equipment and guarantee thermal comfort for the building's occupants. However, HVAC systems have been multi-component systems, for proper maintenance demands a well-planned and strategic approach of maintenance. To this effect, this paper sought to nature, frequency, and the pattern of maintenance of the components units of the HVAC system and its energy implication using the HVAC installation of Hotel buildings in Owerri. It was pursued through the use of a structured questionnaire administered to 384 respondents comprising of the maintenance officers and facilities managers of the 115 Hotels studied. A total of three hundred and forty-two (342) questionnaires were returned adequately filled. The responses were analyzed using the computer SPSS software version 19. The result revealed among others that: the nature of maintenance is often unplanned with the frequency spanning between 13-18months except at the report of a fault. Also, the most maintained component of the HVAC system is the Air distribution system. This was closely followed by the 'Chillers'; 'Ventilators' 'Piping System'' among others ranked in the order of maintenance preference. Thus, the study recommends among others: Uniformity in the maintenance of all the HVAC component units, the use of an Automatic thermostat as against the common On/off toolbox' in the control of the HVAC system to achieve a definite and lasting control of the energy consumption.

Keywords: Component Unit Maintenance, Energy Implication, , Maintenance of HVAC

Introduction

One of the primary essences of maintenance management in any organization is to reduce or even avoid corrective maintenance by proper planning and implementation of maintenance tasks at the right time. And for multi-component systems like the Heating Ventilation and Air Conditioning (HVAC) system, its maintenance requires a well-planned maintenance decision approach that will help the maintenance officer or facilities manager take expert maintenance decisions (Au-yong et al. 2014).

The Maintenance of HVAC facilities is one of the fundamental activities responsibilities of the facilities manager. HVAC maintenance as an intrinsic part of building maintenance (BM), is a basic requirement to keep HVAC running and prevent any sudden failure that can bring the whole system out of acceptable operating conditions. Some of the reasons why it's expedient to properly maintain the HVAC system include; energy savings, decreasing maintenance costs, prevent hazardous conditions, increase the service life of HVAC equipment, and guarantee thermal comfort for building occupants. However over, time the challenges experienced in troubleshooting HVAC problems is traced to the fact that HVAC systems are configured from basic types of components, such as dampers, fans, valves, and coils, and there are usually multiple instances of the same type of components performing different functions in an HVAC system (Yang & Ergan, 2014).

According to Pérez-Lombard *et al* (2008), there has been the intensification of energy consumption in the HVAC systems, which has now become essential in parallel to the spread in the demand for thermal comfort which is no longer considered a luxury as it used to be. It is the largest energy end-use both in the residential and Public Buildings sectors, comprising heating, ventilation, and air conditioning. Its predominance is obvious compared with other energy end-uses in the building.

The energy consumption of an HVAC system though influenced by the performance and operational parameters of the system also largely depend on the characteristics of the heating and cooling demand along with the thermo- dynamic behavior of the building. The actual load of the HVAC systems is less than it is designed in most operating periods due to building behavior (Vakiloroay, 2014). Therefore, the most important factor that contributes to HVAC energy usage reduction in a given building is proper control of the heating and cooling demand (Jin, 2007).

HVAC systems always suffer from various types of faults, since they have large amounts of equipment, actuators, sensors, and controllers. Knowledge of the ins and out of the HVAC system can help prevent expensive breakdowns and unwanted repairs while keeping the system performing at an optimal level. It is estimated that 10%–40% of the HVAC energy consumption can be reduced by removing faults timely (Schein, Bushby, Castro, & House, 2006). Similarly, studies have shown that in a large physical systems, it's also possible to reduce the costly machine failure, equipment downtime, and decrease revenue by keeping abreast of the most effective and current maintenance techniques

This paper assesses the maintenance of the component units of the HVAC installation because the system is multicomponent with a view of establishing the component given less or more attention and its energy consumption implication. This will enlighten clients and facilities managers on the possible savings that can be made from adequate maintenance of the compartments of the HVAC in Hotels during the operational life of the system given the fact that the efficiency of the new HVAC system can be sustained over time with proper maintenance of the installation. (Boardman *et al*., 2005; Sunikka, 2006). Hence, by improving the maintenance of HVAC installation and ensuring uniformity in the maintenance of the compartment of the installation, a decrease in energy consumption can be actualized. Lowering operation costs for businesses as well as reducing greenhouse gas emissions can be realized. The study covers the Hotels with theOwerri municipal only, residential buildings were not considered.

2.0 Literature Review

2.1 HVAC System Components

The HVAC system is a set of components that work together to provide conditioned air to an occupied space to maintain the desired comfort level (Sugarman 2005) As shown in (Fig.1), the HVAC system is made up of the following: chillers, boilers, hot water pump, piping, pipes, valves, dampers, air handling unit (AHU) (ASHRAE 2012), (Handbook 2009). The composition may vary depending on the type of the HVAC system, however, Fig1 presents some of the major components that concern pretty much all HVAC systems.

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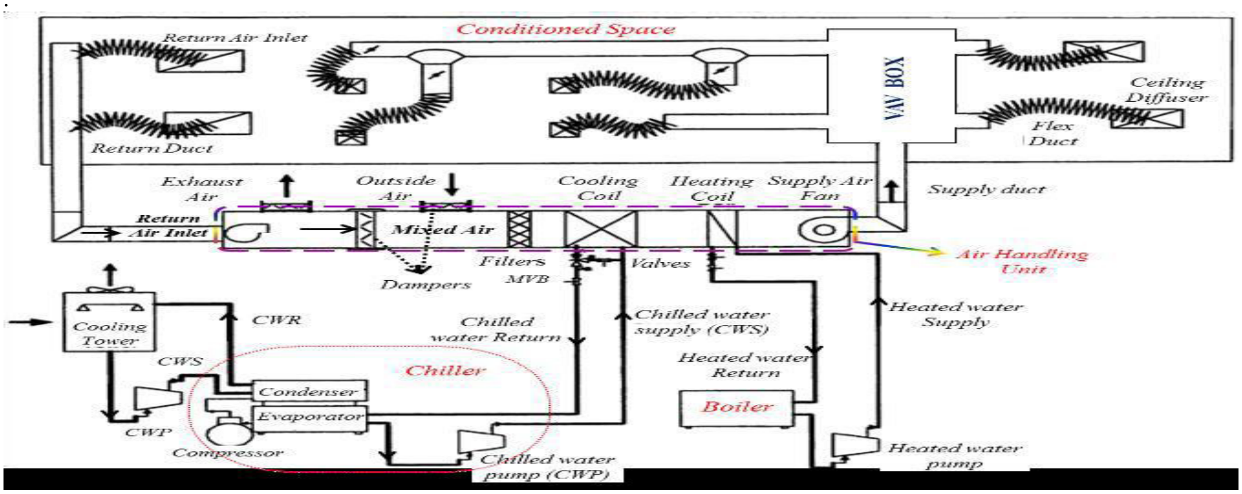

Fig 1: Major Component of the HVAC installation
Source: (ASHRAE 2012), (Handbook 2009).

2.1 The major components of HVAC systems.

A. Thermostat

The temperature sensor on a thermostat indicates when the heater or air conditioner should be running or turned off. It is required that in positioning the thermostat, it must be sited somewhere as far as possible from areas of concentrated temperature difference with the mean temperature of the intended space.

B. Heat Generator

The Heat generator is one of the major components of the HVAC system that is responsible for the generation of heat, by extracting fuel energy inside a furnace/combustion chamber. The hot flue gases will then provide heating for the air or another fluid such as water that will later heat the air entering the conditioned environment.

C. Heat Exchanger

Heat exchangers receive the heat generated in the heat generation unit and transfer it to another fluid. Some control units will activate the furnace or electric heating elements when needed to regulate the air temperature passing through the heat exchanger.

D. Blower

The blower forces air through the heat exchanger into the air ducting that would take the warm air to where it is intended. The blower is driven by an electric motor by a shaft. The modification of the motor speed (varies from one motor to another) can help in adjusting the flow of the air.

E. Condenser Coil or Compressor

The compressor or condenser coil which is normally placed outside is the component that dissipates heat from the warm refrigerant gas to the outside environment and turns it into liquid form. This liquid refrigerant is then taken to the evaporator coil through copper or aluminum tubes. A fan will increase the amount of air flown past the coils and boost the condensation process.

F. Evaporator Coil

The evaporator is located indoors and receives the condensed refrigerant liquid from the compressor. The liquid refrigerant is atomized by spraying nozzles that increase the rate of refrigerant evaporation when it comes to contact with the room's warm air.

G. Air Ducts and Vents

The air is transferred to viaducts to reach different HVAC system components. Good ducting is essential to have high-quality air delivered to the zone. Duct leakage could result in noise when the system is working. In addition, when the air ducting is not in good shape, odor and excess moisture could fill the air.

2.2 Common Maintenance Issues with HVAC Systems

According to Wang, (2013), the maintenance issues, including cooling tower fouling, boiler/chiller fouling, and refrigerant over or undercharge, temperature sensor offset, outdoor air damper leakage, outdoor air screen blockage, outdoor air damper stuck at the fully open position, and dirty filters were investigated in the study he conducted using field survey data and detailed simulation models. The result presented a sample of some of the HVAC maintenance issues (see Table 1) which further prompts the quest to inquire about the impact of maintenance of HVAC parts on energy consumption

Table 1: List of sampled HVAC maintenance issues

Maintenance Type	Maintenance Issues	Impacts
Sensor Calibration	Supply air temperature sensor (SAT) offset	controls, heating, and cooling energy
	Zone temperature sensor offset	
	Outdoor air temperature sensor offset	
Filter replacement D	Dirty filter	pressure drop, fan energy, airflow
Heat exchanger cleaning/treatment	Fouled cooling tower	efficiency
	Chiller: fouled tubes	efficiency
	Boiler: hard water scale	efficiency
	Fouled heating /cooling coil	Efficiency comfort
Mechanical repair	Outdoor air damper leakage	heating and cooling energy
	Stuck outdoor air damper (OAD)	heating and cooling energy
	Clogged OA screen	outdoor airflow is less than 100% during economizer mode thus increasing cooling energy
Refrigerant charge	Chiller: over or under 10% refrigerant charge	efficiency

Source: Wang, 2013

3.0 Research Methodology

This section describes the method adopted for the execution of this study, it entails target population, data collection, and the method of data analysis.

3.1 Population of the Study

The population of this study constitutes all the hotels in Owerri municipal. According to the Jumai Hotel reservation outlook, there are a hundred and sixty-one (161) hotels within Owerri municipal even though are several others within the state.

3.1.1 Sample, Sample size and techniques

In this particular study, the population being studied is the Hotels in Owerri Municipal. There are one hundred and sixty-one (161) hotels within Owerri municipal. Hence the study

However, Cochran's sample size calculation procedure was employed to determine the appropriate sample size in this study. To do this, Cochran's return sample size formula is first determined using the formula presented in equation 1 (Cochran, 1977)

For the number of hotels to be evaluated from the population of 161hotels, the formula (1) was applied

$$\mathbf{n= (N/ (1+N (\alpha^2)} \text{..............................} (1)$$

Where;

n = the desired sample size

N = the Known Population size

Given that the number of hotels in Owerri Municipal is 161 Hotels, the formula below can be adopted. Consequently, the number of hotels is determined as thus,

N = 162, $\alpha = 0.05$

Hence,

Sample size n = $[(161)/ (1 + 161 (0.05)^2) = 114.7$

Hence = 114.7
Consequently, 115 Hotels were studied, however aside from the Hotels, the specific number of respondents were drawn from the 115 Hotels studied, and to determine the number of respondents, equation 2 (sample size formula for an unknown population (Staff and occupants of the Hotels)

$$N_0 = (z^2pq)/d^2 \cdots\cdots\cdots (2)$$

Where;
N_0 = the desired sample size
z = the ordinate on the Normal curve corresponding to or the standard normal deviate, usually any of the following determined based on the 'margin error formula'
For this study, a confidence level of 95% was adopted owing to the fact that the questionnaire was geared towards evaluating perception on monitoring
ii) A 95% level of confidence has $\alpha = 0.05$ and critical value of $z\alpha/2 = 1.96$..
P= the proportion in the target population estimated to have particular characteristics (normal between the range of 0.1 to 0.5
q = 1.0-p
d = degree of accuracy corresponding to the confidence level and Z selected.
Consequently, the sample size is determined as thus,
z = 1.96, d = 0.05 where p = 0.5, q =0.5
N_o= (1.962X0.5X0.5)/ (0.05)2= 384
z = 1.96, d = 0.05 where p = 0.5, q =0.5
N_o = (1.962X0.5X0.5)/ (0.05)2= 384
Thus, after calculating using Cochran's formula for a sample size of 384 respondents

Hence, the study considered 115 Hotels within Owerri Municipal, and as such a minimum of three hundred and eighty-four (384) respondents were drawn from this one hundred and fifteen (115) hotels. Table 3.1 shows the major roads linking the various areas in Owerri Municipal and the corresponding areas along the road where the various hotels for this research were selected.

Table 2: Major Roads Linking Various Areas In Owerri Municipal Where The Hotels Were Selected

S/N	MAJOR ROADS IN OWERRI MUNICIPAL	Area of coverage	Number of hotels to be sampled
1	Port Harcourt Road	Obinze, Avu, Oforola and Ihiagwa, New Owerri	20
2	Naze-Aba Road	Nekede, Agbala and Ulakwo	19
3	Egbu Road	Egbu, Awaka, Ihitta and Emekuku	19
4	Owerri-Orlu Road	Akabo and Obazu, ikenegbu, Prefab, Akwakuma, orlu	19
5	Okigwe – Road	Orji, and Amatta,, Ugwu orji	19
6	Irete-Onisha Road	Orogwe, Amakohia and Ogbaku Egbeada	19
	Total		**115**

Source: Google map, 2018

In choosing the population frame for the respondents and hotels, for this study, a multi-stage sampling technique was employed. In this case, samples are selected in stages (i.e. selection of the areas to be studied first, followed by hotels and then respondents). The respondents are the Staff of the hotels this approach is so in a bid to gather pertinent information concerning the management, scheduling, controls, operations, and maintenance of the HVAC systems. . Nineteen (19) Hotels were selected from each of the five (5) areas identified from the connecting roads within Owerri Municipal with exception of the Port Harcourt Road where twenty (20) were selected as it links more areas.

3.2 Method and Instrument of Data Analysis

The data collected for this study were subjected to various statistical analyses using the computer-based software "Statistical Package of Social Sciences" (SPSS) version 19. The results of the analysis were presented in the form of a table for easy comparison and clear expression of the findings. Also, data obtained through questionnaires were analyzed using the mean score, Relative Importance Index.
The Mean Score was computed using this formula:
Mean-score = $(X_1W_1+X_2W_2+X_3W_3+ \ldots X_nW_n)/N$ ....(3)
Where
W = Weight of answer choice

X = Response count for answer choice
N = Total Numbers of the Respondents

From the computation, the most significant constraint factor in a subset was one with the highest Mean-Score value. The factor having an average or higher value is considered significant as shown in Equation 1, while the insignificant factors are identified using Equation 2.

Significant constraint factor: MR > 2.5 ....(i)
Non-significant constraint factor: MR < 2.5 .... (ii)

Where:
$1 < M < 5$ on 5-point Likert rating scale

Based on the mean score (M) values of the constraints in a given set, the variable was ranked or rated.

RII ranges between zeros to one. The five-point Likert scale ranking was transformed to relative Importance Indices (RII) for each of the construction contract documents. The weighted average for each item was determined and ranks were assigned to each item, representing the perception of the respondents

Relative Importance Index (RII)

$$= \frac{\sum fx}{\sum f} \times \frac{1}{k} \quad \text{...} \quad (4)$$

Where,
∑fx = is the total weight given to each attribute by the respondents.
∑f = is the total number of respondents in the sample.
K = is the highest weight on the Likert scale.

Results are classified into three categories as follows (Othman et al, 2005) when;
RII<0.60 -it indicates low frequency in use
0.60≤RII<0.80 -it indicates high frequency in use.
RII≥0.80 –it indicates very high frequency in use

4.0 PRESENTATION AND ANALYSIS OF QUESTIONNAIRE

A total of three hundred and ninety questionnaires were administered to respondents within the area of study. The percentages of responses are presented in Table 3 below. From the table, it can be gathered that a total of three hundred and forty-two questionnaires were received adequately filled giving a percentage response of 87.7%.

Table 3: Questionnaire administered

Questionnaires	Frequency	Percentage of (%)
Number returned	342	87.7
Numbers not returned	48	12.3
Total	**390**	**100**

Source: Field Survey, (2020)

4.1.6 HVAC Maintenance

Table 4: HVAC Maintenance

S/N	Variable	Option	Frequency (No)	Percentage (%)
1	Is there planned maintenance for HVAC systems in the building	a) Yes	98	28.7
		b) No	234	68.4
		c) Don't Know	10	2.9
		Total	**342**	**100**
2	schedule for the planned maintenance	a) 0-6mnths	22	6.4
		b) 7-12 months	94	27.5
		c) 13-18 months	45	13.2
		d) Over 18 months	156	45.6
		e) Don't Know	25	7.3
		Total	**342**	**100**
3	Who is in charge of HVAC system service maintenance	a) Building operator	138	40.4
		b) Maintenance contractor	204	59.6
		c) Nobody	-	-
		Total	**342**	**100**
5	the elements covered by the maintenance or services contract	a) Services or maintenance duration	34	9.9

	b)	Filter Replacement or clean up	45	13.2
	c)	Duct clean up	56	16.4
	d)	Replacement of faulty units/parts	54	15.8
	e)	Refrigerant recharge/change	35	10.2
	f)	Purging of system	31	9.1
	g)	Review of HVAC system performance and operational/ energy efficiency	87	25.4
	Total		**342**	**100**

Source: Field Survey, (2020)

The opinion of the respondents' on the maintenance of the HVAC systems in the hotels and the result is as presented in Table 4. From the Table, it can be seen that there is no planned maintenance of the HVAC systems as attested by 68.4%. In line with the maintenance interval, 45.6% of the respondents attested that the HVAC is maintained in an interval of over 18thmnths; 27.5% claim it's within 7-12months while 13.2 % claim it is 13-18 months.
The result also shows that most of the HVAC system maintenance is done mainly by maintenance contractors (59.6%) while only 40.4% of the respondents claim it is done by building operators in the Hotels. The researcher also sought to know the elements covered by the maintenance or service contract. From the result, it can be seen that 25.4% of claim its Review of HVAC system performance and operational / energy efficiency; 16.4% 'Duct clean up'; 15.8% 'Replacement of faulty units/parts'. Details of other elements covered by the maintenance service contract are as shown in the table.

4.1.7 Ranking of Maintenance of the HVAC Components

Table 5: Ranking of Maintenance of the HVAC Components

S/N	Maintenance of the HVAC Components	WEIGHTING/RESPONSE FREQUENCY										
		1	**2**	**3**	**4**	**5**	**(∑f)**	**∑fx**	**MEAN**	**Std**	**RII**	**RANK**
A	**Chillers**											
1	Check refrigerant level, leak test with an electronic leak detector. If abnormal, trace and rectify as necessary, Inform department in writing on the rectification	50	61	14	173	44	342	1126	3.29	1.33	0.66	4TH
2	Inspect the level and condition of oil. If abnormal, trace the fault and rectify it as necessary. Inform department in writing on the rectification	-	63	51	228	-	342	963	2.82	0.79	0.56	5TH
3	Check the liquid line sight glasses for proper flow	-	106	-	140	96	342	828	2.42	1.19	0.48	8TH
4	Check all operating pressure and temperature	142	08	73	119	-	342	853	2.49	1.34	0.50	7TH
5	Inspect and adjust, if required, all operating safety controls	-	81	14	138	109	342	1301	3.80	1.13	0.76	1ST
6	Check capacity control, adjust if necessary.	50	187	105	-	-	342	739	2.16	0.66	0.43	9TH
7	Lubricate vane/ linkage/ bearings.	-	04	158	110	70	342	1272	3.72	0.80	0.74	2ND
8	Visually inspect the machine and associated components, and listen for unusual sound or noise for evidence of unusual conditions.	-	46	94	170	32	342	1214	3.55	0.84	0.71	3RD
9	Check lock bolts and chiller spring mount.	-	238	22	49	33	342	903	2.64	1.05	0.53	6TH
10	Review daily operating log maintained by department's operating personnel Review daily operating log maintained by department's operating personnel	77	265	-	-	-	342	607	1.77	0.42	0.35	10TH
Cluster statistics		**32**	**106**	**53**	**113**	**38**			**3.06**	**1.21**		
B	**WATER PUMPS**											
1	Inspect all water pumps	88	98	35	46	75	342	948	2.77	1.51	0.55	3RD
2	Check all seals, glands and pipelines for leaks and rectify as necessary.	113	75	67	37	50	342	862	2.52	1.42	0.50	5TH
3	Re-pack and adjust pump glands as necessary	145	43	69	85	-	342	778	2.27	1.25	0.45	6TH
4	Check all pump bearings and lubricate with oil or grease as necessary.	67	98	11	116	50	342	1010	2.95	1.41	0.59	2ND

5	Check the alignment and condition of all rubber couplings between pumps and drive motors and rectify as necessary.	92	78	23	135	14	342	927	2.71	1.34	0.54	4TH
6	Check all bolts and nuts for tightness and tighten as necessary.	14	98	16	167	47	342	1161	3.39	1.16	0.68	1ST
Cluster Statistics		**86**	**82**	**37**	**98**	**39**			**2.77**	**1.39**		
C	**AIR HANDLING UNITS AND FAN COIL UNITS**											
1	Inspect all air handling and fan coil units	75	33	54	79	101	342	1124	3.29	1.52	0.66	1ST
2	Check all air filters and clean or change filters as necessary.	54	114	23	134	17	342	972	2.84	1.24	0.57	3RD
3	Check all water coils, seals and pipelines for leaks and rectify as necessary	88	89	46	98	21	342	901	2.63	1.30	0.53	5TH
4	Check and re-calibrate modulating valves and controls. Adjust and rectify as necessary to ensure compliance to the original specifications	91	73	34	124	20	342	935	2.73	1.35	0.55	4TH
5	Purge air from all water coils.	102	113	12	67	48	342	872	2.55	1.44	0.51	7TH
6	Check all fan bearings and lubricate with grease as necessary.	91	121	8	72	50	342	895	2.62	1.43	0.52	6TH
7	Check the tension of all belt drives and adjust as necessary.	156	70	15	34	67	342	812	2.37	1.59	0.47	9TH
8	Check and clean all the condensate pans, trays and drains.	78	67	55	97	45	342	990	2.89	1.38	0.58	2ND
9	Check, clean, and service smoke detectors. Carry out a system test to ensure that the smoke detector will trip the AHU‘s.	135	64	43	78	22	342	814	2.38	1.37	0.48	8TH
Cluster Statistics		**97**	**83**	**32**	**87**	**43**			**2.70**	**1.43**		
D	**AIR-COOLED PACKAGED UNITS AND PRECISION COMPUTER AIR-CONDITION EQUIPMENT**											
1	Check condenser fan motor load ampere	131	56	43	89	23	342	843	2.46	1.39	0.49	6TH
2	Check fan and motor mounting brackets	123	76	56	87	-	342	791	2.31	1.20	0.46	8TH
3	Check shafts and bearings. Lubricate with grease as necessary.	145	45	54	67	31	342	820	2.40	1.42	0.48	7TH
4	Check the tension of all belt drives and adjust as necessary.	112	34	66	45	85	342	983	2.87	1.59	0.57	2ND
5	Check for refrigerant leaks with electronic leak detector.	109	76	35	77	45	342	899	2.63	1.46	0.53	4TH
6	Check electrical terminals and contactors operation and connection for tightness.	45	66	34	165	32	342	1099	3.21	1.24	0.64	1ST
7	Check compressor motor current	109	49	41	118	25	342	927	2.71	1.41	0.54	3RD
8	Check refrigerant line driers and moisture indicators	90	88	71	77	16	342	867	2.54	1.23	0.50	5TH
Cluster Statistics		**108**	**61**	**50**	**91**	**32**			**2.64**	**1.40**		
E	**AIR DISTRIBUTION SYSTEM**											
1	Check operation of all modulating and fixed dampers controlling airflow through the unit. Lubricate all damper bearings and linkages as necessary.	54	45	78	98	67	342	1105	3.23	1.34	0.65	1ST
2	Check noise level of discharged air from diffusers	77	56	34	87	88	342	1079	3.15	1.53	0.63	2ND
Cluster Statistics		**66**	**51**	**56**	**93**	**76**			**3.18**	**1.43**		
F	**VENTILATION**											
1	Check and adjust as necessary that the airflow of all fans complies with the original specifications.	81	67	56	94	44	342	979	2.86	1.37	0.57	4TH
2	Check the tension of all belt drives and adjust as necessary	76	45	76	88	57	342	1031	3.01	1.40	0.60	3RD
3	Check and lubricate all fan bearings	91	67	56	101	27	342	932	2.73	1.34	0.55	5TH
4	Tighten motor terminals.	71	34	54	89	94	342	1127	3.30	1.49	0.66	1ST
5	Check starter contacts	34	109	52	78	69	342	1065	3.11	1.32	0.62	2ND
Cluster Statistics		**71**	**64**	**59**	**90**	**58**			**3.00**	**1.40**		
G	**SWITCHBOARD**											

1	Clean and adjust all switch gear, contactors, relays and associated electrical equipment at intervals not exceeding six months	56	45	112	97	32	342	1030	3.01	1.20	0.60	1ST
2	Check and prove operation of thermal over load and protection devices.	154	35	56	86	11	342	791	2.31	1.35	0.46	4TH
3	Check and ensure tightness of all equipment fastenings and cable terminations within switch boards	132	56	31	77	46	342	875	2.56	1.51	0.51	3RD
4	Vacuum clean all switch board cubicles	112	53	67	78	32	342	891	2.61	1.39	0.52	2ND
Cluster Statistics		**114**	**47**	**66**	**85**	**30**			**2.62**	**1.39**		
H	**PIPING SYSTEM**											
1	Check all piping system for leaks and repair these where they have occurred	67	72	45	97	61	342	1039	3.04	1.41	0.61	1ST
2	Check for damage & deterioration of insulation or sheathings. Rectify as necessary	58	76	79	92	37	342	1000	2.92	1.27	0.58	2ND
Cluster Statistics		63	74	62	94	49			**2.98**	**1.34**		

Source: Field Survey, (2020)
Where: ND= Never Done; RD= Rarely Done; NI= No Idea; OD= Often Done; AD= Always Done

The Likert scale result in Table 6 presents the ranking of the maintenance of the HVAC component. From the result in the Table, the HVAC component. is divided into various Components namely: Air Distribution System (with cluster mean value of 3.18 and standard deviation of 1.43), Chillers (with cluster mean value of 3.06 and standard deviation of 1.21), ventilation, Switch Board (with cluster mean value of 3.00 and standard deviation of 1.40), Piping system (with cluster mean value of 2.98 and standard deviation of 1.34), Water Pumps (with cluster mean value of 2.77 and standard deviation of 1.39), Air Handling Units and Fan Coil Units, Air-cooled package units and precision computer air-condition (with cluster mean value of 2.64 and standard deviation of 1.40), and Switch Board' (with cluster mean value of 2.62 and standard deviation of 1.39), all arranged in the order of preference based on the mean value. From the cluster mean value it indicates that of all the various components of the HVAC system, the Air Distribution System is the component that is often maintained compared with the other component based on the mean.
However, within the various section of the HVAC system, the following are the result of the ranking of the maintenance of the various component that makes up the HVAC system

a) In the chillers, the respondent ranked "Inspect and adjust, if required, all operating safety controls" (RII=0.76) as the most carried out maintenance practice for the chillers. This was closely followed by "Lubricate vane/ linkage/ bearings: (RII=0.74), "Visually inspect the machine and associated components, and listen for unusual sound or noise for evidence of unusual conditions" (RII= 0.71), and "Check refrigerant level, leak test with an electronic Leak detector. If abnormal, trace and rectify as necessary, Inform department in writing on the rectification (RII=0.66) which ranked second, third and fourth respectively. Details of the ranking of other factors that relate to the chillers as a component of the HVAC system are presented in the Table.
b) In the Water Pumps, the respondents ranked "Checking all bolts and nuts for tightness and tighten as necessary" (RII=0.68) was ranked the first as the most maintained aspect of the water pump. This was also followed closely followed by: "Checking all pump bearings and lubricate with oil or grease as necessary" (RII=0.59) and "Inspection of all water pumps" (RII=0.55), which ranked second and third respectively. Details of the ranking f another maintenance aspect of the Water Pump are as presented in the Table.
c) In the Air Handling Units and Fan coils, Units; "Inspection of all air handling and fan coil unit" (RII=0.66) was ranked first. "Checking and cleaning all the condensate pans, trays and drains" (RII=0.58) was ranked Second while "Checking all air filters and clean or change filters as necessary" (RII=0.57) was ranked third. Details of the ranking of another maintenance process of the Air Handling Units and Fan coil units are as presented in the Table.
d) In the Air Cooled Packaged Units and Precision Computer Air Conditioning Equipment, the respondents ranked "Checking electrical terminals and contactors operation and connection for tightness"(RII=0.64) as the first while the lease ranked maintenance procedure is "Checking fan and motor mounting brackets" (RII=0.46). Details and ranking of other maintenance procedures are as shown in the Table.
e) In the Air Distribution System, "Checking the operation of all modulating and fixed dampers controlling airflow through the unit. Lubricate all damper bearings and linkages as necessary" (RII=0.65) was ranked the first
f) In the Ventilation Component of the HVAC system maintenance, "Tighten motor terminals" (RII=0.66) was ranked first. While "Check starter contacts" (RII=0.62) and "Checking the tension of all belt drives and adjust as necessary (RII=0.60) were ranked the second and third commonly done maintenance practice on the ventilation component of the HVAC systems in the Hotel respectively. Details of the ranking of other procedures are presented in the Table.
g) In the Switch Board, the respondents ranked "Cleaning and adjusting all switchgear, contactors, relays and associated electrical equipment at intervals not exceeding six months" (RII=0.60) as the common practice maintenance procedure of the Switchboard in the Hotels. The details of the ranking of other procedure of the Switchboard is presented in the Table

h) Finally in the Piping system as a component of the HVAC system, “Checking all piping system for leaks and repair these where they have occurred” (RII=0.61) was ranked first while “Checking for damage & deterioration of insulation or sheathings. Rectify as necessary” (RII= 0.58) was ranked Second.

5.0 SUMMARY OF FINDING

The result revealed that there is no planned maintenance of the HVAC systems, and with regards to the maintenance interval; maintenance is only carried out when there are reports of faults, and in few places where there is routine maintenance carried out the interval spans as much 18months in average.

Regarding the pattern of maintenance of the HVAC system components, the common maintenance actions of the components are as presented: for the Chillers (“Inspection and adjustment of all operating safety controls”, “Lubrication of vane/ linkage/ bearing”, “Visually inspection of the chillers and associated components, for an unusual sound or noise for evidence of unusual conditions” and “Check on the refrigerant level, leak test with an electronic leak detector. If abnormal, trace and rectify as necessary”).

In continuation, the result also revealed the following: Checking all bolts and nuts for tightness and tighten as necessary”; Checking all pump bearings and lubricate with oil or grease as necessary” and “Inspection of all water pumps” as the ranking of the common maintenance check for the water pump as the component of the HVAC system in the Hotels. Still, on the maintenance of the component of the HVAC systems, the result also revealed that the common check is frequently done on the Air Handling Units are: “Inspection of all air handling and fan coil unit”; “Checking and cleaning of all the condensate pans, trays and drains”; and “Checking all air filters and clean or change filters as necessary” arranged in their order of severity.

Still, on the maintenance of the various component of the HVAC system, the result also revealed that the most frequent maintenance checks carried out on the Air-Cooled Packages Units and precision Computer air conditioning equipment are: “Checking electrical terminals and contactors operation and connection for tightness” and “Checking fan and motor mounting brackets. Similarly, the most frequent maintenance checks carried on the Air Distributions System are: “Checking the operation of all modulating and fixed dampers controlling airflow through the unit. Lubricate all damper bearings and linkages as necessary”.

In furtherance, the study revealed that “Tightening of the motor terminals”; “Check starter contacts” and “Checking the tension of all belt drives and adjust as necessary” are the basic and frequent maintenance often carried out in the Ventilation Component of the HVAC system. It was also discovered that maintenance checks such as: ranked “Cleaning and adjusting all switchgear, contactors, relays and associated electrical equipment at intervals not exceeding six months” is the most common maintenance checks carried out on the Switch Board of the HVAC system as a component. Lastly, on the maintenance of the various component of the HVAC system it was revealed that “Checking all piping system for leaks and repair” and “Checking for damage & deterioration of insulation or sheathings. Rectify as necessary” are the most frequent and reoccurring maintenance checks conducted on the Piping System of the HVAC in the various hotels assessed.

5.1 CONCLUSION

1. The maintenance of the HVAC components is usually not planned and is only carried out at demand or report a fault. Also, in very few Hotels where there is routine maintenance the average interval of the maintenance spans as much as 18months. This account for the energy wastage as the use of the faulty system has energy implication.
2. The pattern of maintenance of the HVAC component system revealed that the most maintained component of the HVAC system is the Air distribution system. this was closely followed by the ‘Chillers’ (Mean= 3.06); ‘Ventilators’ (Mean= 3.00) and ‘Piping System’’ (Mean= 2.98) which ranked second, third and fourth respectively While an overview of the common maintenance check in each of the components are as follows:
    a) the Chillers (“Inspection and adjustment of all operating safety controls”, “Lubrication of vane/ linkage/ bearing”, “Visually inspection of the chillers and associated components, for an unusual sound or noise for evidence of unusual conditions” and “Check on the refrigerant level, leak test with an electronic leak detector. If abnormal, trace and rectify as necessary”).
    b) the Water Pump (Checking all bolts and nuts for tightness and tighten as necessary”; Checking all pump bearings and lubricate with oil or grease as necessary” and “Inspection of all water pumps”)
    c) Air Handling Units are (“Inspection of all air handling and fan coil unit”; “Checking and cleaning of all the condensate pans, trays and drains”; and “Checking all air filters and clean or change filters as necessary” arranged in their order of severity).
    d) the Air-Cooled Packages Units and precision Computer air conditioning equipment are (“Checking electrical terminals and contactors operation and connection for tightness” and “Checking fan and motor mounting brackets)
    e) the Ventilation Component (“Tightening of the motor terminals”; “Check starter contacts” and “Checking the tension of all belt drives and adjust as necessary”)
    f) the Switch Board (“Cleaning and adjusting all switchgear, contactors, relays and associated electrical equipment at intervals not exceeding six months”)
    g) The Piping System (“Checking all piping system for leaks and repair” and “Checking for damage & deterioration of insulation or sheathings. Rectify as necessary”)

5.2 RECOMMENDATION

A. Planned maintenance with a shorter routine interval (less than the common 18months interval identified) will help in ensuring proper functionality of all the HVAC system components and also avoid energy wastage. The study strongly discourages maintenance only on a report of a fault on any component of the system.
B. Uniform maintenance attention should be given to all the components of the HVAC system as the entire components are interdependent and need to work together as an entity to avoid energy wastage
C. As much as possible definite attention must be given to the HVAC control component to ensure that there is no form of fault such as bad temperature sensors connection to (Direct Digital Control) DDC and faulty Selector switch connection to DDC at any point in time in hotels.
D. The study also recommends the use of an Automatic thermostat as against the common On/off toolbox' in the control of the HVAC system to achieve a definite and lasting control of the energy consumption of the HVAC systems in the Hotels in Owerri

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Management of Recovered Wastewater for Passive Irrigation of Buildings Green Landscaped Areas: Blue/Green Roof Subterranean Water Management System

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ABSTRACT

Countries in the Middle East region, including United Arab Emirates (UAE) are amongst the most water-scarce countries facing water management challenges due to rapid population growth and urbanization, and Dubai is a strong example. Currently, the resident population of the emirate is 3.42 million, expected to increase to 5.8 million by 2040. Dubai has an average water consumption in excess of 550 liters of water per person. The primary source of freshwater is desalinated seawater from the Arabian Gulf as it accounts for 89.9% of the city's water supply needs. Dubai 2040 Urban Master Plan for sustainable development promises the best environment and infrastructure required to enhance the community's happiness and wellbeing through adopting greener areas. Life within the surrounding environment counts on the water as a vital natural resource, and smart management of water is integral to the success of the future master plan. Recovered water usage from condensate, greywater, Treated Sewage Effluent (TSE), and rainwater to reduce the requirement on potable water supply is essential, in addition to the energy required to treat and distribute potable water. Irrigation water systems implemented throughout the region are predominantly overground drip-feed, sprinkler, and manual handheld hose systems. This paper investigates delivering recovered wastewater to a shallow subterranean storage system, where water is then transferred on-demand to the growing medium by passive capillary action. Passive Irrigation is a method of growing plants and grasses using inert porous medium to transport water and oxygen to the root zone by capillary action.

Key Words: Water scarcity, Water management, Passive Irrigation

INTRODUCTION

Dubai, one of the seven emirates of the UAE, has grown rapidly to become the most populated city in the region according to the World Population Review (2021). Currently, the population in Dubai is 3.4 million as estimated by the Dubai statistics center (2021), which is subjected to an increase of 2.4 million in the next 20 years, representing around a 71% increase of the current population (Almasar, 2021). This increase explains Dubai Electricity and Water Authority (DEWA) efforts for adapting and supporting many conservation programs and initiatives, such as 'Let's Make This Summer Green 2021' campaign found to encourage residents to utilize smart solutions for energy and water conservation. Moreover, recent results have shown accumulated savings of 2.2 terawatt-hours (TWh) of electricity and 7.8 billion gallons of water during 2009 and 2019 (DEWA, 2020).

Recently, many Gulf regions have announced their long-term plans to determine the future development of their own countries, emphasizing healthier and more sustainable objectives such as Oman's Vision 2040, Dubai's Vision 2040, and Saudi Arabia's Vision 2030. These proposed 'visions' incorporate common related goals directed toward enhanced sustainable infrastructure, having a more developed economy, improving a healthier environment and quality of living, and lastly the well-being and happiness of the residents.

The limited existence of water sources in the Arab region is one of the major problems facing sustainable development as reported by Richard et al. (2003), due to many factors including; the nature of the arid climate of the country, which plays a significant role in the water resources availability (Murad et al, 2007), in addition to rainfall, being the main natural source for charging surface water and groundwater storage, has extremely irregular events in time and space, finally, high temperatures in the region lead to high evaporation rates that reduce the amount of surface water available. All mentioned factors directed the actions toward the use of fresh underground water. Noreddine et al. (2012) explained that to overcome challenges associated with heavy pumping of groundwater that leads to deteriorated groundwater levels, many desalination plants have been placed in various parts of the country to cover the increased water demands required by the expanding population and economy of the UAE. Desalination is required to supply the continued reduction of water storage needed to ensure continued potable water to support the development of the country.

The general aim of this document is to discuss and highlight the use of a passive subterranean irrigation technique for the Arab Region to encourage the development of more sustainable landscaped areas. The document will investigate how recovered wastewater can be reused for irrigation in a more economical way, taking into account environmental, social and public health concerns. Recovered wastewater can be more cost effective if it can be distributed more adequately and without having to be treated to a high level to overcome any harmful effects to the local workforce and populace. Understanding concerns relating to the use of recovered wastewater by professionals and local municipalities or governments, and signifying how these concerns can be mitigated will be discussed within the document.

This report will emphasise the need to develop research trials in the region to further understand the type and condition of wastewater required to develop and maintain healthy vegetation growth, the nature of local soils, vegetation root zone, and finally rainwater attenuation.

RESEARCH METHODOLOGY

The research strategy will begin with secondary research of existing data via a literature review and will highlight the use and advantages of a proprietary passive capillary subterranean irrigation system.

Information is known about the proprietary geocellular system being proposed, however, it is not fully understood how the academic research, based on temperate climate and soil conditions will fully perform in an arid environment.

The theory requires both descriptive and numerical data, therefore a combined quantitative and qualitative research approach using 'live' trials and monitoring is preferred to gain a realistic understanding of the environmental and climatic conditions experienced in the Middle East region. The combination of the two approaches will be more effective in defining the effectiveness of the system and define a realistic and economical alternative approach to current irrigation practices.

LITERATURE REVIEW

In this literature review, current facts and challenges of water resources will be discussed in addition to current irrigation methods, and how alternative passive irrigation technique using subterranean water management systems can help to limit many environmental and health concerns.

Water Scarcity

Many factors affect the availability of freshwater, and the main reason behind modulating the natural hydrological cycle is the human development, as it led to the changeability of the familiar earth's climate system along with the modification of the land surface. Water resources are also influenced by increased population growth, economic development, and dietary changes, all of which have a major impact water demand and consumption.

The increased demand for water to grow food, supply industries, and sustain growing urban and rural populations has led to a rising scarcity of available freshwater in many regions. Governments, corporations, and communities are concerned about water supplies' future availability and sustainability (Lim K. et al, 2019).

Water scarcity prevails in regions with high population density and/or in regions with high usage of irrigated agriculture such as India, eastern China, and the Nile delta. High water scarcity levels also transpire in regions that are not densely populated or with concentrated irrigated agriculture but with very low natural water availability (Mekonnen M. and Hoekstra A., 2016), such as in the world's arid areas; Sahara, Gobi, and Central Australia desert.

Water scarcity is typically represented as a relationship between water availability and the human population (Rijsberman F., 2005). (Falkenmark et al.,1989) pointed that an area is experiencing water stress when annual water supplies drop below 1,700 m3 per person. When annual water supplies drop below 1,000 m3 per person, the population faces water scarcity, and below 500 cubic meters of absolute scarcity, as illustrated in Figure 1.

The concept of water stress is based on situations where insufficient water for all uses, whether agricultural, industrial, or domestic based on statistical records about water use and efficiency. Figure 1 indicates how many countries within the Arab peninsula are in absolute water scarcity, as the average amount of water available per person is less than 500m^3 per year.

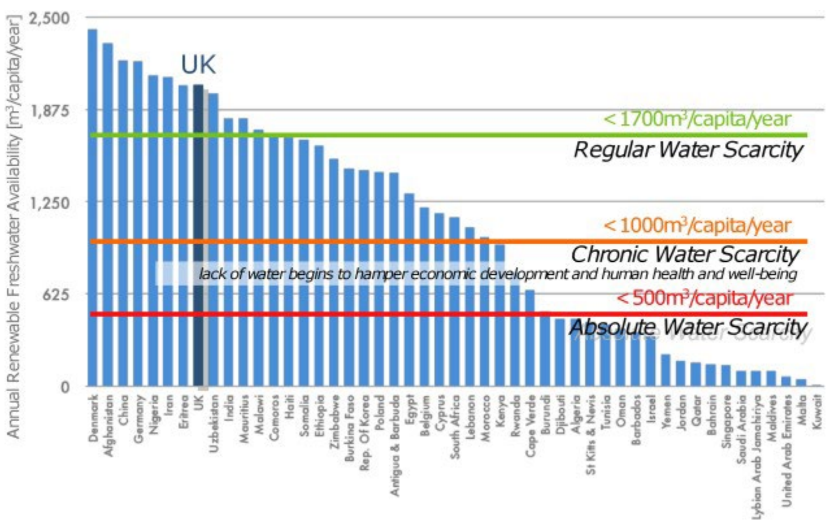

Figure 1. Annual Renewable Fresh Water Availability for Different Countries by University of Nottingham

Water consumption per person, on the other hand, is some of the highest globally their populations increase there will be a need for more food and proportionally less water available per person.

Water used for agricultural use is relatively high in comparison for its use for domestic; as it needs nearly 70 times more water to grow food for people than is used for domestic purposes and most of the water used for domestic purposes is returned as wastewater. Only a small proportion of the potable water, around 9% supplied to our homes used for drinking and cooking, and the rest of the supply does not reach drinking quality (A waterwise briefing, 2007).

In many countries, domestic water is not supplied through separate pipes for different applications, therefore, high-quality treated water is unnecessarily used for low-quality-required requirements.The agricultural sector is by far the largest user of water in the world, however, the efficiency of water use in agriculture is poor at around 45% with more than 50% water losses. Improved efficiencies would generate vast water saving compared with the industrial and domestic water sectors (Hamdy R.et al, 2003).

According to Water Security Strategy (2036) announced by the UAE goverment, the thermal desalination is the dominant technology to make seawater potable due to the limited natural water resources. And today, 70 major desalination plants produce potable water, which presents around 14% of the world's total production of desalinated water (Robert M., 2020). In his research, Thomas (2012) illustrates how it becomes a challenge to 'Green the desert' considering the limited resources of water while looking after the multiple benefits of green spaces in all aspects of sustainable design.

Table (1) identifies the increase in desalinated water usage and the ongoing reduction in groundwater usage in the UAE.

Table 1. Water Consumption (MIG) by DEWA (2020)

Water (Total System Requirmenet)	Units	2019	2020
Desalinated Water	MIG	126,121	125,685
Groundwater	MIG	477	466

According to Sharif et al. (2012), the natural sources of freshwater is limited to groundwater in the UAE, which has led to increasingly resorting of desalinated water that is been produced using excess heat from electricity generation.

Desalination has had a major impact on the marine environment from discharging highly concentrated seawater to the Arabian Gulf as stated by Thomas (2003).Globally, we need to seriously re-think our approach to freshwater from how much water do we need and from where do we get it? but rather: how much water is there and how can we best benefit from it? The challenge is to promote a strategy that aims at the effective management of the demand aspect of water, and not at continued supply-oriented water management (Faklenmark, M.et al, 1989). In absolute water-scarce regions such as the Arab Region, the reuse of treated water is becoming essential for meeting associated excessive demands. Therefore, the reuse of treated wastewater will help in reducing the requirement for expensive desalinated water production and the pressure on depleting groundwater withdrawal. It will also reduce the environmental impacts allied with these forms of water sources (Aleisa & Al-Zubari 2017).

Water Recovery and Reuse

Domestic water conservation can be improved in all types of residential, institutional, and commercial buildings in the Middle East. Installation of products like faucet aerators, low-flow or sensor-based faucets, low-flow showerheads, low-flush and composting toilets, water-saving dishwashers, and clothes washers can play a significant role in saving water at the domestic level (Zafar, 2021).

One of the main concerns about the use of treated waste water is water quality and the effect on Public Health. Toze (2006) describes the main concerns as being the variety of microorganisms including, pathogens, viruses, bacteria, protozoa and helminths, which all carry infectious disease. These organisms can be readily removed from the wastewater due to advancements in water treatment. Used in conjunction with traditional wastewater treatment processes the use of membrane filtration and UV disinfection has increased in both municipal waste water treatment plants and within individual buildings.

Water recovery (harvesting) and reuse can be explained as the collection, treatment, retention (storage), and reuse of water, this can be from freshwater supplies or wastewater processes. There are many ways to recover and reuse water; the following investigates several techniques that are currently being used for water recovery and reuse and their impact on our daily lives. Rainwater recovery (harvesting) has a long tradition going back for thousands of years (Ferrand E A. & Cecujanin F, 2014). The collection of rainwater has been used for collecting and storing rainwater from rooftops, land surfaces, or rock catchments using simple techniques such as natural and/or artificial ponds and reservoirs to provide water for drinking, domestic, and agricultural needs for many centuries (Abdulla F A. & Al-Shareef A W., 2009).

Rainwater recovery and its reuse for building irrigation purposes are limited, however, during prolonged dry periods it is feasible to use the buildings' wastewater and/or municipally Treated Sewage Effluent (TSE) supply to provide irrigation water instead of treated potable water. In many of the hot and humid regions of the world, modern buildings utilize mechanical air conditioning systems, buildings such as hotels, residential blocks, retail malls commerce, and industrial units .

Moreover, air conditioning systems operating with elevated external dew point temperatures will produce a substantial amount of condensed water from the chilled water heat exchanger that needs dispose of (Bryant J A. & Ahmed T, 2008), then the liquid condensate is generally drained into a pipework system to be discharged into the foul drainage system.

The quality of recovered condensate can be purer in content than tap water with total dissolved solids (TDS) as low as 15mg/l, compared with desalinated potable water produced by either multi-stage flash or reverse osmosis processes having a TDS between 50 and 300 mg/l after post-treatment processes (Loveless K J., & Farooq A., 2012). In addition to the need to test some condensate water sine, it can have high PH and conductivity levels which can be addressed using low-cost polishing treatment processes.

Taking Burj Dubai as a good example, standing tall amidst The Park, an 11-hectare green oasis that surrounds the foot of the tower. The Park has six spectacular water features, lush green gardens, and colorful flowering trees. An estimated 67.5 million liters of water a year is generated from the building, enough to fill 20 Olympic-sized swimming pools (At The Top, Burj Khalifa. Fact Sheet, 2016).

Most water applications provide wastewater, in urban areas the recovery and reuse of grey water is utilised on individual buildings or on larger municipal scales.

Greywater is water originally supplied as wholesome water that has already been treated and used for bathing, laundry or washing dishes. The collected water is filtered and treated (if required) and stored for re-use supplying non potable applications such as WC Flushing, car washing, laundry and irrigation.

Blackwater is water originally supplied as wholesome water that has already been treated that is discharged as sewage containing human waste. The collected water can be collected and treated and reused for non potable applications such as irrigation. The use of Treated Sewage Effluent (TSE) can help conserve natural water resources and the level of treatment provided will determine the final use.

One of the main concerns about the use of TSE is water quality and its effect on Public Health. Toze (2006) describes the main concerns as being the variety of microorganisms including, pathogens, viruses, bacteria, protozoa, and helminths which all carry infectious diseases. These organisms are removed from the wastewater during the recycling treatment process. TSE is already playing a significant role in supplementing the water demand in the Arab Region, particularly for irrigation (Jasim.S et al, 2016). Safely treated wastewater now exceeds renewable freshwater resource volumes in Kuwait, the United Arab Emirates, Qatar, and Bahrain.

Figure 2 illustrates how many Arab states are using the latest technologies and Artificial Intelligence in the production of renewable freshwater and safely water treatment.

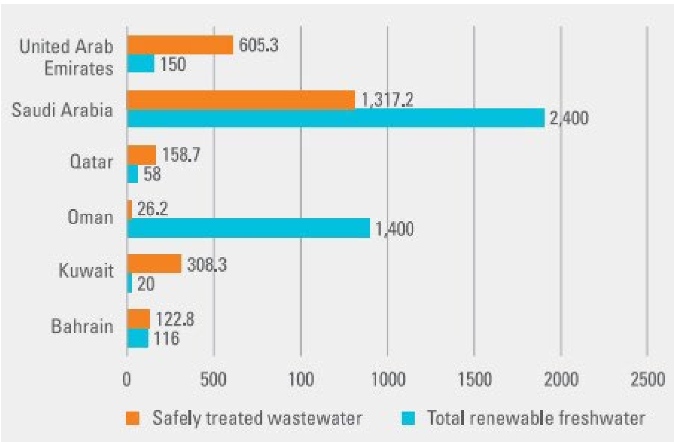

Figure 2. Illustration of Safely Treated Wastewater Relative to Renewable Freshwater Resources in Selected Arab States (MCM/Year)

Passive Irrigation

Spray irrigation of gardens or landscaped podiums/roofs consumes approximately 12-15 liters of potable water per m^2 every day (In garden, 2020). When using spray irrigation (sprinkler systems) in a country as arid as the UAE, 60% of the water evaporates before it is absorbed by the plants (Dakkak, 2021). The remaining water intended for irrigation is not evenly distributed. This lack of uneven distribution coupled with the decrease in the amount of water used can also be detrimental to the plants' health. Sprinkler systems on the other hand, create aerosol or droplets that can be easily inhaled by landscape workers and the general public, particularly during moderate to high wind speeds. Wind also creates water pattern distortions and increases evaporation losses (Hamdy. 1992). However, as awareness about water scarcity increases, more efficient irrigation methods are being used on landscaped podiums and roofs as an alternative to spray irrigation.

Drip irrigation consists of perforated tubes placed along the floor or buried near the roots of plants, 40-60cm below the surface , which provides water directly to the plant roots. The result is not only a drastic decrease in the amount of water evaporated, but also uses 25-35% less water than spray irrigation systems (Zafar, 2021).

The landscaped area is constructed above the structural slab or in raised planters and then lined with a water-proof layer followed by layers of gravel and soil. A dripping pipe is installed in the gravel layer and protected to let water flow and prevent clogging from fine silts. This method only requires around 2.5 liters of water/m^2/day in order as opposed to 12-15 liters (Dakkak, 2021). This method of irrigation requires the soil in the root zone to have high horizontal permeability to permit free lateral movement of water. For uniform distribution of water percolating into the soil, the drip pipes need to be closely spaced, say at about 0.5m. This method of irrigation is expensive with an uneven distribution of subsurface moisture (Rather, 2020)

Automatic drip irrigation is effective at supplying pre-regulated amounts of water directly to the soil with reduced water loss due to evaporation or runoff. It is particularly good for mulched areas because it can directly soak the soil without washing away the mulch.An alternative method of irrigation is to provide water from a shallow subterranean storage vessel while at the same time allowing for water management of rainfall. Utilizing recycled polypropylene geocellular storage system with high void ratios of circa 95% and having a high structural compressive strength.

Polypropylene modular attenuation units are joined together system to create a horizontal structural raft (Wilson, S. et al, 2005).
Using local rainfall data and Intensity-Duration-Frequency Curves the geocellular attenuation system is designed to provide adequate attenuation during the required project rainfall event, for example, 24hr/100-year rainfall event.

Incorporating attenuation at podium and roof level(s) creates smaller catchment regional areas and allows effective flow control and management of the drainage system. The attenuation storage layer will incorporate flow control outlet(s), restricting the flow of surface water entering into the site-wide stormwater drainage system.

Flow controls are installed to ensure surface water is held back and temporarily stored. Each orifice is sized to give a proportion of the discharge rate appropriate to the drained area (sub-catchment) and the available storage volume. Orifice plates are used as they are simple flow control devices that restrict the flow of surface water through a conveyance system by narrowing the area the water can flow through at the entry to collecting pipework.

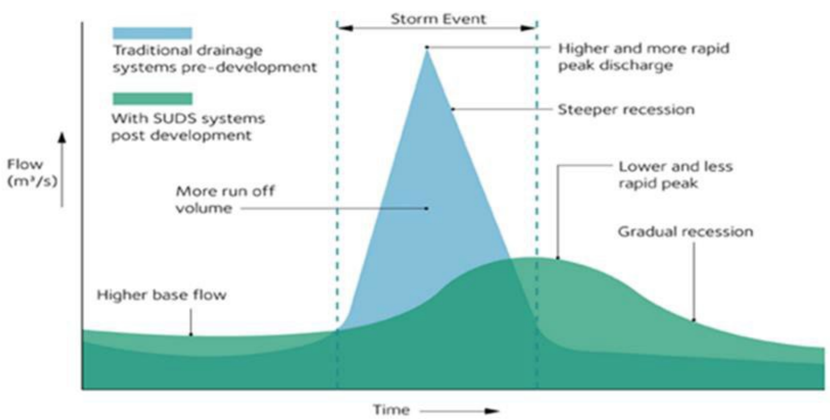

Figure 3. Illustration of Traditional vs attenuated rainfall profile by CIRIA SuDS manual C753

They are particularly appropriate in shallow drainage systems where the effect of large differences in hydraulic head on flow rate is negligible. The restricted flow will discharge into the sitewide stormwater drainage system and can also be recovered and reused in the sitewide irrigation system. Managing rainfall as close as to where it falls (source control), aims to maximise water storage within the site to encourage attenuation,treatment, infiltration, and evapotranspiration.

Capturing and attenuating rainfall at the source reduces the impact on the development and surrounding infrastructure, slowing, storing, and restricting the flow can help to reduce the need for offsite conveyance and mitigating off-site flooding events. Figure 3 from CIRIA SuDS Manual C753 illustrates the traditional vs. attenuated rainwater event profile.

The geocellular attenuation cells are not fully filled with wastewater and naturally incorporate an air reservoir that provides oxygen into the growing medium and the root zone. Until they acclimatize, vegetation produces increased levels of carbon dioxide, (CO_2) into the atmosphere. Using indigenous grasses and vegetation and/or pre-acclimatized plants will allow plants to establish more quickly and reduce the amount of CO_2 emitted (King A.W., et al, 2006).

Passive Capillary Irrigation is a method of growing plants and grasses using the natural process of capillary rise, driven by evapotranspiration, drawing water from the storage reservoir to the active root zone. Therefore, supplying water on demand (CRC for Water Sensitive Cities, 2020), Figure 6.

Moreover, the attenuated system can be integrated into a green podium/roof design, wastewater can be delivered and stored within the geocellular system to provide Passive Irrigation of green spaces creating amenity, recreation, biodiversity, and enhanced well-being. As illustrated through the cross-section below, the hollow structural columns within the geocellular units are filled with an absorbent Rockwool (capillary cones) which draws up treated wastewater or rainwater stored within the unit, refer to Figure 4.

The geocellular raft is covered with a proprietary wicking geotextile drawing wastewater from the Rockwool columns and transport the water horizontally across the structural raft to irrigate the growing medium, Figure 5 shows the placement of the wicking geotextile and Rockwool columns. The wicking geotextile controls the wastewater required to provide optimum irrigation of the root zone. The most benefit in terms of irrigation is that the amount of water stored will be calculated to suit the soil permeability and daily water required to sustain the growth of the proposed flora/vegetation, not allowing to cause any inappropriate irrigation rates.

The capillary rise within the geocellular attenuation system and overlying soils can be considered in two parts, the first is that provided by the system itself; Water is transported via the capillary columns to the top of the attenuation layer and into the overlying wicking geotextile assuring that at this level the geotextile is constantly 55-65% saturated with water.

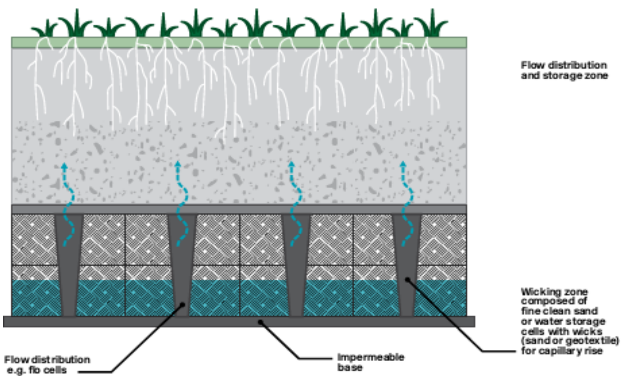

Figure 4. Cross Section Illustration of the Subterranean Water Management System

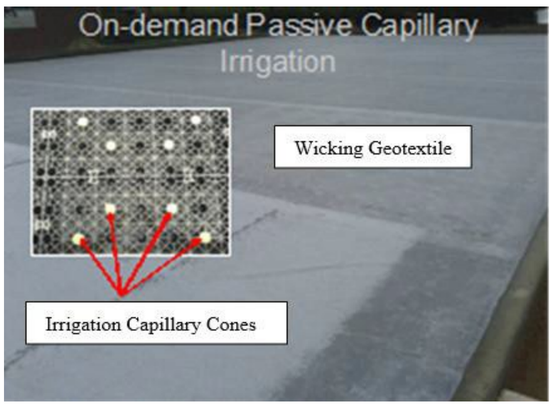

Figure 5. Illustration of On-Demand Passive Irrigation through Capillary Cones on site

The second part is achieved within the overlying soils and its capacity to transport water from the lower elevation to a higher elevation driven by the hydraulic head gradient acting across air/water interface. This will determine the maximum height water content and rate of capillary rise (Lu et al, 2004, Li et al, 2018).

Current research and testing of the system by the Sports Turf Research Institute (STRI Group). In addition to field testing that has been taking place at Bingley in the UK on temperate grasses and at Brisbane in Australia on hot climate grasses. The trials have been taking place simultaneously with laboratory testing, the information collated has then been used to adapt the external trials to regulate the water required to provide optimum irrigation of the root zone.

The tests have incorporated several different grass types, types, and depths of growing medium and the regulation of flows required to develop and maintain vegetation and grasses. The testbeds assess the health and root growth of natural turf using a variety of soil and grass types and depth of geocellular storage irrigation tanks

Several relevant observations have been recorded from the testing regime; capillary rise is very dependent on grain-size-distribution, organic matter content, and soil depth. Small differences in these factors within a standard soil type can have a significant effect on the capillary rise; for example: the smaller the average grain size in the soil the higher the capillary rise, the greater the variability in particle size (mix of small and larger particles) the higher the capillary rise, and the greater the organic matter content in the mix the higher the capillary rise.

In very general terms; the capillary rise can vary from as little as 1 mm in a single-sized course (50 mm+) rounded river gravel, 100-200 mm in sand-based soils, to more than 600 mm in very fine clayey soils.

Soil moisture content (SMC) slowly decreases with the increase in height above the wicking geotextile, which is actually beneficial as plants can grow their roots in the zone with the most appropriate SMC. Providing there is a reservoir of water in the attenuation units, the Soil Moisture Content Does NOT change during a dry spell, The wicking geotextile also acts as a root barrier. The challenge is to identify and utilise a soil mix that offers the desired SMC; The water content in very sandy soil may vary from 3% to 10% from the driest condition to the wettest drained state or from 20% to 40% in a clay soil (Brandt et al, 2017).

One of the prominent results to date is that the roots grow down towards the water source and are stronger and more robust. Flora and vegetation planted within the growing medium still have access to minerals and nutrients, minimizing the requirement for fertilizers and helping to develop a healthy root system. This is a major benefit regarding maintenance of landscaped areas at podium and roof level(s). Supplementary active irrigation may be required during the establishment stage of the podium/roof green landscaped areas to ensure satisfactory initial growth.

FINDINGS AND DISCUSSION

The benefits of passive irrigation can be considerable (CRC for Water Sensitive Cities, 2020, Mackay Queensland State Government, 2018, E2Design lab et al 2017) . Passive irrigation is a natural process and requires no additional energy, thereby reducing energy requirements which could be considerable across a green city. Shade, evapotranspiration and insulation provided by greening helps to reduce the impact of extreme temperature events and reduce peak energy demands. Reduce reliance on potable water supplies and the energy consumed by de-salination. Less energy usage reduces the carbon footprint of a city. Reduce demands on existing stormwater networks and help mitigate off site flooding.

Support landscapes with alternative water sources to increase landscape health and resilience. Private building Podiums and Roofs can be part an integral part of the solution when it comes to recreational space requirements. Creation of attractive, accessible green spaces encourage greater levels well-being. Contact with nature improves mood and lowers levels of stress, anxiety and depression. Vegetation reduces greenhouse gases through sequestering carbon dioxide. Leafy vegetation improves air quality and can achieve local microclimate cooling benefits.

Reducing the urban heat island (UHI) effect. Increasing the vegetation cover and permeable soil surfaces in cities provides shade and thermal insulation reducing the amount of heat absorbed and released by the hard surfaces, thereby cooling the cities during the day and overnight.

Many countries in the Arab region are increasing investment for the recovery and reuse of safe waste water, particularly the production of Treated Sewage Effluent (TSE). Advances in treatment technology incorporated alongside traditional waste water methods can provide safe waste water use for highways and public realm irrigation, groundwater injection and agricultural irrigation.

The production use of TSE can help the Arab countries work towards their vision(s) of improving the environment, resilience in extreme climates and the overall quality of living.

Smart Urban Rooftops & Urban Areas

Green Podiums and roofs are an important climate adaptation tool for cities. They manage rainwater, mitigate flood events, increase biodiversity, improve air quality and can help reduce the urban heat island effect. Extreme weather conditions experienced in the Arab region such as very high temperatures and long periods of drought can have a major negative impact on the vegetation limiting the variety of plants than can survive.

Utilising advanced digital technology can alleviate this problem by optimizing the water availability in and around green roofs by constantly monitoring the vegetation health, watering needs and available water. Combining sensors, actuators and Internet of Things (IoT) with predictive models and ‘live’ weather data it is possible to detect when plants have insufficient water. Smart systems linked to the building waste water recovery system(s) can automatically water the soft landscaped areas (Credit Valley Conservation. 2018).

Conversely, if a heavy rainfall event is predicted that could lead to localised flooding, the podium/roof attenuation system can be drained/emptied at a restricted flow to provide the required storage capacity to protect the building and surrounding catchment area.There are a few systems currently being trialled that are connected to open data platforms and can provide ‘real time’ data for building management teams and municipal waste water departments.

CONCLUSIONS AND FURTHER RESEARCH

It is also important to reflect on the recovery of waste water at the micro level, individual buildings within the urban environment. During its daily usage each building will produce black water, grey water, condensate and seasonally, rainwater. It is possible to recover, treat and reuse some or all of these waste waters within the building, greatly reducing the reliance on expensive and in many areas environmentally unfriendly desalination potable water. The recovery of waste water is already designed into many buildings in the region with the main reuse being for irrigation purposes via traditional irrigation methods.

Based on the current research there is clearly an environmental, social and economic value to the integration of a high strength shallow sub surface water management system for passive capillary irrigation for water stressed areas to develop pleasant 'green spaces' on podium and roofs.

The starter section should provide a synopsis of the article as well as the background and context of the paper. Starting from general to the specifics, this section should provide a rationale that substantiates the research. This can be done by providing evidence of difficulties that needs solution and / or identified knowledge gap in a specific domain, level, geographical location, society, and industry. As the response, a clear research agenda can be described specifying research aim and objectives to clarify the purpose of conducting the investigation.

A well designed system can provide a consistent structural sub base incorporating a high void ratio providing attenuation, storage, passive irrigation and also incorporating an air reservoir to provide oxygen into the root zone more effectively.These systems also mitigate any Public Health issues for landscape workers and the general populace as contact with waste water is removed, there is no spray irrigation producing possible harmful aerosols, and no direct contact with waste water associated with hose and drip feed irrigation systems.

Further investigation is now required through local trials to determine the optimum system requirements, soil conditions, water regulation, grass/plant species etc. to provide sustainable 'healthy green spaces' within the building footprint, building upon the information already accumulated through existing research.

Additional investigation may also be merited to understand the minimum treatment required for recovered domestic waste water as it may be possible to achieve an optimum irrigation supply using waste water that has only received membrane and disinfection treatment; this may be possible as direct human contact using a geocellular subsurface irrigation system is minimised, if not eliminated.

It would also reduce the energy required to produce the higher tertiary grade waste water currently required for over ground sprinkler and drip feed irrigation systems.

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Track 3

Internet of Things (IoT) Applications

Computational Infrastructure Design to Support Applications in Intelligent Building Environments – Case Study Focused on Intelligent Laboratories

Live VR: Realtime Virtual Reality is Architecture Practice on Air

Real-time Monitoring and Control

Developing Bluetooth Communication Technologies for Safer Construction Sites: Experiences and Learnings

Sustainability and the Environment

Urban Sustainability Transformation through Building Adaptive Pathways

Design for Smart BE

Studying Buildings Outlines to Assess and Predict Energy Performance in Buildings: A Probabilistic Approach

Computational Infrastructure Design to Support Applications in Intelligent Building Environments – Case Study Focused on Intelligent Laboratories

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Abstract
The Internet of Things (IoT) has provided a significant increase in the number of devices connected to the Internet, which need to be managed by a computing infrastructure. Usually, these computational infrastructures are designed for large-scale applications, which often involve proprietary solutions and high acquisition and maintenance costs. Based on the bibliographic study, we defined what is IoT applications of a small, medium, and large scale, then we propose an architecture for small and medium scale applications. Our main contributions with this work are found in the mapping of the information flow of these architectures, proposal of a PaaS for managing the medium-sized architecture, providing an extensible architecture according to the addition of smaller architectures, it also shows an approach aimed at complexity of the solution from the bottom up, that is, from simpler applications to more complex applications. A case study carried out at University of São Paulo's LaSDPC using open source technologies covered a small environment (laboratory) and a medium environment (building). Finally, it is concluded that the advantage of this approach is a centralized service platform, in which new services can be integrated.

Keywords
Architectures; Internet of Things (IoT); Platform-as-a-Service;

1 Introduction

Bansal and Kumar (2020) present a new vision of devices, gateways, operations systems, middleware, and communication used in Internet of Things (IoT) environments. It is noted in this work the composition heterogeneity in IoT environments and the necessity to define architectures for different environments.

Given the heterogeneity of devices, they are used in different areas of knowledge such as wearable, smart home, smart vehicles, smart infrastructure, smart healthcare, agriculture, manufacturer, supply chain, logistics, social and business applications (Goyal et al. 2021). In addition to this heterogeneity of applications, they can also be scaled by size (Sunhare et al. 2020).

Sunhare et al. (2020) conducted a study on IoT and data mining and presented a relationship between small and large IoT applications that can be seen in Figure 1. The block in red presents applications of small scale, which are used with a base to build smart homes. Smart buildings in turn serve as a basis for the development of Smart Transport and Healthcare. Finally, Smart Transport and Healthcare serves as the basis for the creation of Smart Cities. Therefore, we can observe the correlation between the most diverse types of applications and how simpler applications serve as a basis for creating more complex applications.

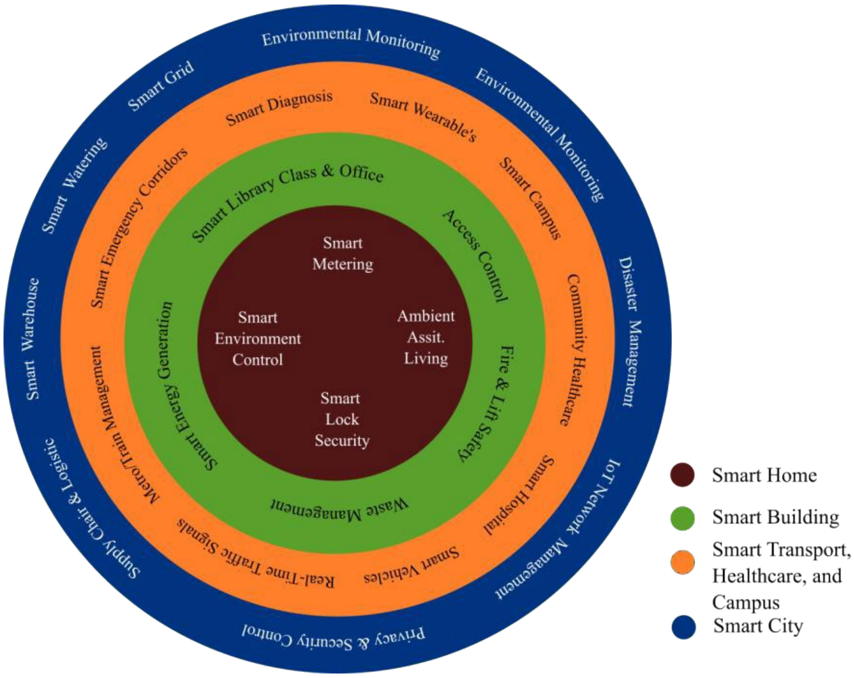


Figure 1. Small-scale to large-scale IoT applications. Adapted from Sunhare et al. (2020).

In this work, we treat smart homes as small-scale environments, smart buildings, smart transport, healthcare, and campus as medium-scale environments, and Smart Cities as large-scale environments.

Our work will address a gap that exists in small and medium scale IoT architecture projects that allow them to be scalable. For this, we use a PaaS that is responsible for managing the small architectures while serving as the core of a medium architecture.

This work is organized as follows. Section 2 presents the bibliographic analyses with related works. Section 3 presents two architectures, the first for small applications that do not deal with computational cloud technologies and the second proposed for medium sized applications that interact with computational clouds. Section 4 presents the mapping of implemented infrastructure, the application modelling in the context of this architecture, and the prototype of the physical devices. Finally, Section 5 presents future work and conclusions about this work.

2 Literature Review

For the bibliographical survey, we performed a search in the Scopus database using the keywords of small and medium-scale systems concatenated with words architecture, infrastructure, and IoT. Given a large number of results, we added filters between the years 2015-2021 focusing only on engineering science works. The result of this bibliographical survey is described in the next paragraphs of this section.

Patrono et al. (2020) present the challenges in smart environment solutions. One of these challenges is found in architectures or middlewares, in addition to mechanisms at hardware level capable of guaranteeing interoperability, scalability and adequate performance. Furthermore, there is a need for relevant objects to converse in the same language: HTTP, CoAP, MQTT, Web Services, among others.

Debauche et al. (2020) present an architecture for smart campus focused on interoperability. This architecture use protocols and applications executed in each layer of network architecture.

In turn, in Devyatkin et al. (2020) an architecture for an intelligent department is presented. This approach includes measuring light, energy, ambient, and acoustic measurements. The AMQP, MQTT, TCP, and HTTP protocols were also used for data download. This approach manages to work with a scalable, asynchronous, and debuggable applications.

Table 1 presents bibliographic references resume. We present the application area, that is, for which environment the architecture was proposed. We also present a brief description of the architecture discussed in each of the works.

Table 1. Bibliographic references resume.

Author	Application	Architecture	Advantages	Disadvantages
Refaat et al. (2017)	Smart Air-conditioning System	Presents a solution for control of air-conditioning systems. The components are air-conditioning and a mobile application with an artificial neural network (ANN) for decision making.	Presents a decision make algorithm.	It is an isolated architecture not scalable only for air-conditioning.
Brunete et al. (2021)	Ambient assisted living (AAL) environments	Presents an architecture with a multimodal interface, robots arms, ZWare Gateways, Zolertia Z1, Raspberry PI, 6LowPAN, WiFi, and MQTT. This architecture is highly heterogeneous.	Connection and cooperation of different IoT protocols and components.	The entire application is stored in the main controller. This represents a bottleneck in architecture.
Periša et al. (2021)	Smart Stores	Presents architecture with nodes of fog computing connected with the cloud. Are used for communication machine-to-machine (M2M), 3G, 4G, 5G, and WSN Networks (Wifi, ZigBee, Z-Wave).	Fog and Cloud computing is scalable and can process, synchronize data in real-time or in certain intervals.	The specific components of the cloud computing platform are not detailed.

Li (2020)	Smart Home	Presents six different architectures to monitor real-time smart homes. It uses many sensors, ZigBee interface, Microsoft Kinect v2, and other technologies.	Presents a real-time monitoring smart home with many applications and study cases.	This approach does not present a detailed platform or infrastructure to control these applications. This platform/infrastructure is generalized with services but doesn't have depth as needed.
Debauche et al. (2020)	Smart Campus	Presents an architecture interoperable to a smart campus using solutions for Smart Home. This architecture has some home assistants installed in Raspberry PI 4, ESP32 which communicates directly with the home assistant, and many sensors and actuators.	The use of smart home solutions in the building of smart campus solutions. A complete architecture with components, frameworks, and protocols.	This approach does not present a detailed platform or infrastructure to control these applications.
Slaný et al. (2020)	Smart Metering	It features a simple platform with sensors, a microcontroller, and a high-end device, and a cloud to manage an application. They use a Carrier Board, M2.COM process module, flowmeters, and Raspberry PI as a gateway.	Board creation and integration with other control devices.	This approach does not present a detailed platform or infrastructure to control these applications
This work.	Smart lab expansive for Smart Campus	We present architectures for small-scale and middle-scale applications and make a study case with these architectures. We use the MQTT protocol, ESP32 as a microcontroller, and a Platform as a Service (PaaS) for the management of information.	The advantage of this architecture is a scalable PaaS and the division of middle architectures into small architectures. Small applications can be integrated to construct more complex applications, this work focuses on it.	This work presents just some components and protocols.

Our work analyzes these architectures to create an architecture for Smartlab that can operate on a small and medium scale. So, this architecture can be extended and can be scalable as new features can be added, since we also use PaaS for data control.

3 Small and Medium Systems

As presented by Sunhare et al. (2020) and the proposed definition of small and medium sized systems, we propose in this topic an architecture for small sized that offers support and control of the environment locally, that is, without the need for a cloud or computational architecture. We also propose a mid-range architecture that can integrate small, and isolated architectures.

3.1 Small-Scale Systems

Small-scale Systems do not need a lot of computational power due to their size. The data these systems can be managed for a single High-End Device (HED). This type of HED as show Bansal and Kumar (2020) are single-board computing that has a large number of computational resources such CPU, RAM, flash memory, etc.

To complete the architecture of this type of system it is necessary to use microcontrollers with lower computational capacity, sensors and actuators. Smaller-capacity microcontrollers are responsible for orchestrating data transmission from sensors and actuators. Sensors acquire data from the environment, and actuators perform actions on it. A model representing this type of data flow is shown in Figure 2.

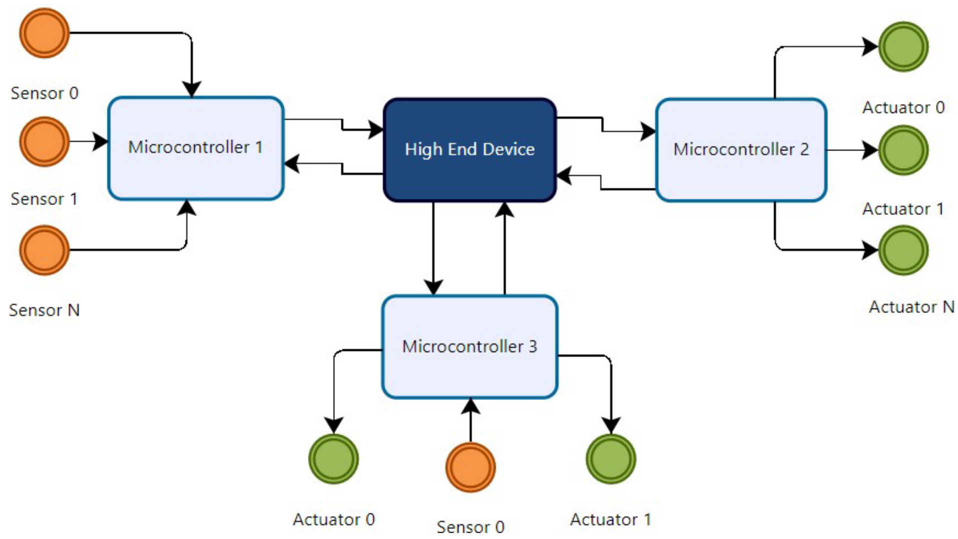


Figure 2. Model for small environment.

Figure 1 shows that each microcontroller can manage between 0…n actuators, and 0…m sensors. All microcontrollers communicate with the HED. This device is responsible for orchestrating the data flows that travel in the architecture, so that all the computation that requires more processing power is performed by a central device.

Communication protocols must be taken into account in this type of architecture. According to the literature review, there are several protocols used and communication formats, which we can mention for AMQP, MQTT, TCP and HTTP.

3.2 Medium-Scale Systems

In middle-scale environments we propose an architecture derived from small-scale environments, but with the addition of a cloud infrastructure layer. This model is advantageous due to the on-demand consumption provided by this type of platform. This means that the outsourcer will only pay for what has been processed/consumed. This architecture can be seen in Figure 3.

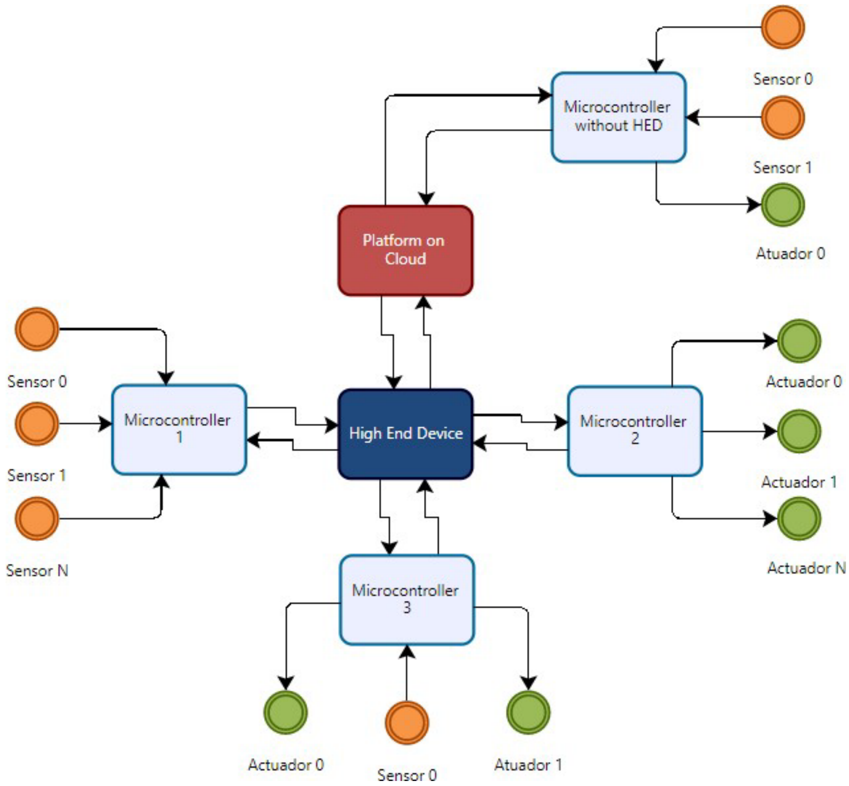


Figure 3. Model for medium-scale environment.

Figure 3 shows an interaction between the components with the addition of a new component named "Cloud Platform". This platform can be defined as a computational cloud that offers a Platform as a Service (PaaS).

PaaS provide an environment with data storage, microservices that control devices, and orchestration, using a distributed event streaming platform (DESP). According to Mineraud et al. (2016), an IoT platform is defined as the middleware and infrastructure that allows end users to interact with smart objects.

PaaS must provide reliable services, low latency and scalability (Salami and Yari 2018). All these features are required in IoT applications. The reliability of the service is related to the service's ability to run considering dealing with failures. Low latencies are necessary to minimize the application response time. And finally, IoT applications must be scalable as new devices are integrated.

In this section we presented two architectures proposed. First for small-scale applications that do not need to communicate with one computational cloud and the other, medium-sized, integrate smaller architectures and manage data in a computational cloud.

4 Infrastructure Model Mapping – Real Case Study

A case study was carried out at the Laboratory of Distributed Systems and Concurrent Programming (LaSDPC) of the Institute of Mathematics and Computer Science (ICMC) of the University of São Paulo (USP). In this case study, sensors were located in the LaSDPC laboratory in order to replicate the rest of this infrastructure on the ICMC campus.

The architecture proposes to manage an intelligent building environment, since the environment is characterized by several smaller intelligent environments, and these smaller environments integrate and grow in complexity. Dividing IoT applications by the type of application, the size of this application and proposing architectures at each scale provides a general and specific view of the challenges that will be faced in developing these solutions. We were able to design an environment controlled by IoT devices, a small architecture that can be used to configure many smaller environments, and a medium architecture that allows the integration of many smaller architectures. The mapping of models allows the construction of environments in an intelligent way, as it simplifies the process of architectural definition and integration of new components.

(1) (2)

Figure 4. Mapping of physical components for architecture as shown in Figure 2.

Figure 4 (1) shows the small-scale environment in which the architecture components were installed. Figure 4 (2) presents an intelligent building environment that has several small-scale applications such as the one shown in Figure 4 (1).

4.1 Infrastructure

Figure 5 highlights the infrastructure with the names of the physical components of the prototype. This infrastructure is an extension of Figure 2 so we map the abstract components to the components used.

Figure 5 presents the components used in the computational edge. We have installed sensors for temperature, humidity, movement and lighting. Infrared actuators are used to turn on/off the air conditioner. ESP32 microcontrollers are used to manage data traffic and manage actions within labs. Note that ESP32 connects directly to a cloud infrastructure and this infrastructure performs data processing and management.

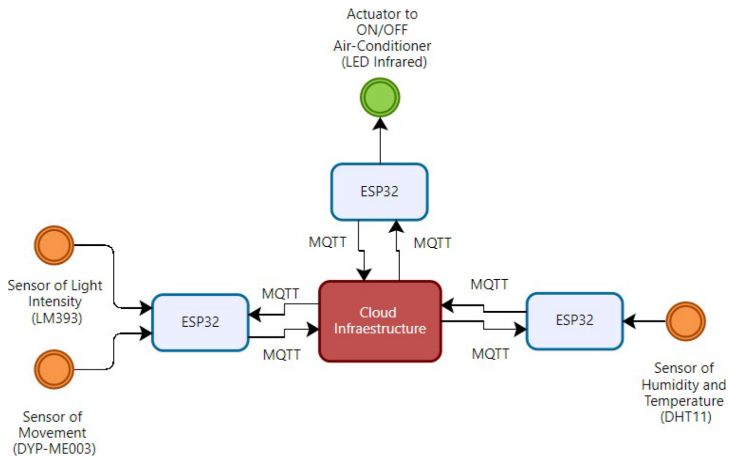


Figure 5. Mapping of physical components for architecture presents in Figure 2.

PaaS is described in Figure 6. External Devices are component that represents the architecture of Figure 5. We can see that the application orchestration is performed in Apache Kafka. Microservices are responsible for processing and acting on the data received. The non-relational database finally stores information from the external devices.

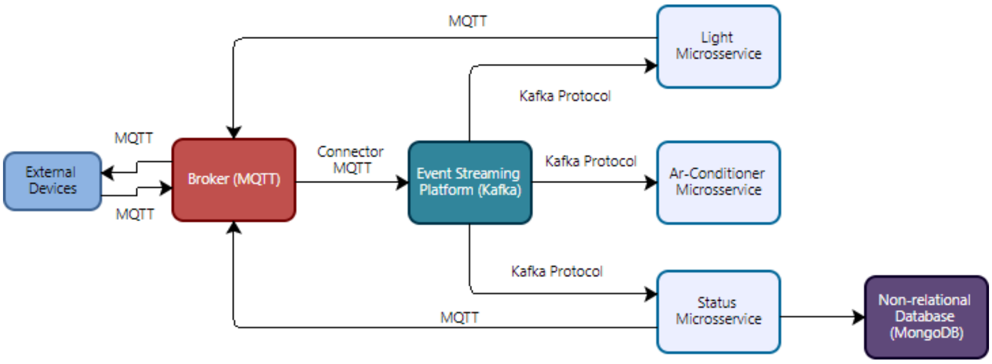


Figure 6. Mapping of PaaS components. Adapted from Bueno (2020).

The information flow in two ways: data generation by sensors, and action executing by actuators. Listing 1 shows the steps between data generation and storage. Listing 2 shows steps between action for executing an event and the event action itself.

Listing 1 Steps between data generation and storage

1 Sensors (humidity, temperature, lighting) takes a measurement.
2 Sensors send the data to a microcontroller (ESP32).
3 The microcontroller makes a treatment on data.
4 The data is sent to a HED (listing 1, step 5) or to PaaS (listing 1, step 7).
5 The data as treated with noise elimination, grouping, or other necessary treatment.
6 HED sent the treated data (information) to PaaS using the communication protocols (MQTT).
7 The Broker (Mosquitto) receives information and sends it to a distributed event streaming platform (DESP)
8 DESP (Kafka) checks if the information triggers an event (listing 2, step 1) and sends it to the microservice (Python).
9 The microservice receives the information and stores it (MongoDB) or sends it back to the broker for further treatment.

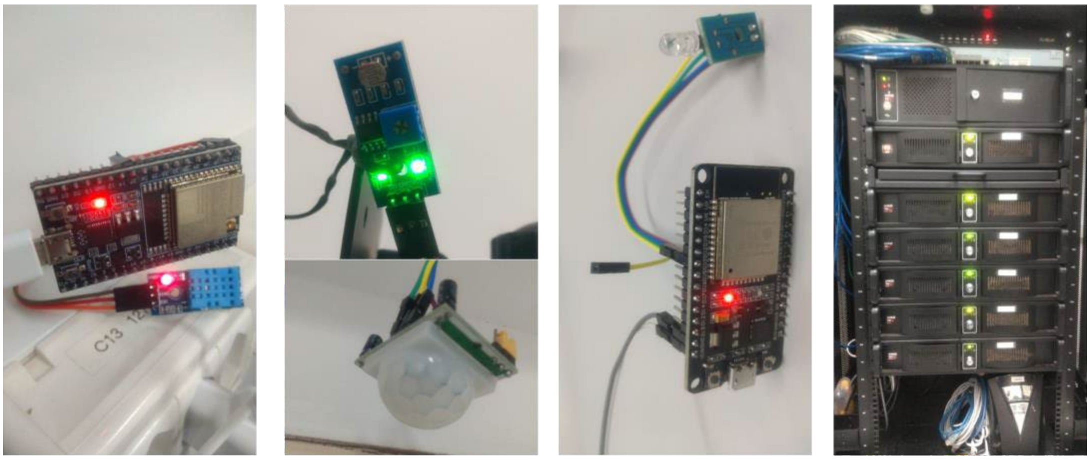
Listing 2 Steps between action for executing an event and the event action

1 An action execution event is fired.
2 The microservice (Python) or DESP (Kafka) dispatches a request.
3 The broker (Mosquitto) receives the request and dispatches it to the specific microcontroller (ESP32) with the actuator.
4 The microcontroller receives the request and executes it.
5 The microcontroller sends the request response to an HED (listing 2, step 6) or the broker (listing 2, step 7).
6 The HED receives the request response and forwards it to the broker.
7 The broker (MQTT) receives the response from the microcontroller and sends it to DESP.
8 DESP (Kafka) checks if the information triggers an event (listing 2, step 1) and sends it to

the microservice (Python).
9 The microservice receives the information and stores it (MongoDB) if necessary.

4.2 Prototype

The ESP32 and sensor suite was installed in the lab. Figure 7 (1) presents the ESP32 and the DHT11 sensor responsible for collecting temperature and humidity data. Figure 7 (2) Introduces the ESP32 and the light intensity and motion sensor. Finally, Figure 7 (3) shows the infrared LED actuator responsible for turning the air conditioner on and off.



(1) (2) (3) (4)

Figure 7. Sensors and Microcontrollers installed on Lab (1-3). LaSDPC private cloud (4).

PaaS was installed on the LaSDPC private cloud (Figure 7 (4)). It is possible to dynamically allocate resources, in addition to being able to distribute a slice of necessary resources according to the application's demand.

In this section we present the components of the architecture proposed in section 3 for medium-scale environments. In addition, we present a PaaS that can adapt to the demands of new devices. Finally, we present the prototypes installed in the laboratory.

5 Conclusions and Further Research

In this work, we present an architecture for small and medium-scale systems. The middle-scale architecture manages to be an extension of several small architectures. A PaaS is introduced to centralize control of these diverse small architectures. Finally, we present an intelligent lab model developed using this mid-range architecture as a foundation. The main advantage of the presented model is its scalability. New devices and features can be easily added so that the application continues to work even in larger environments or in the integration of different environments.

This work contributes by providing an architectural view by application scale so that the mapping of these architectures can be reused and integrated. A mid-range module was proposed with a PaaS that can scale as new, smaller applications are integrated.

As future work, we plan to extend the proposed architecture and add new components and protocols so that it becomes more and more generic. For PaaS we intend to add Analytics. DataStream Engines, log managers and computational intelligence algorithms.

6 Acknowledgement

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VR Live in Architecture: Broadcasting Realtime Virtual Reality

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Abstract
Desktop broadcasting and Virtual Reality is an emerging medium which provides many opportunities in architecture, planning and design practices, including assessment for new architecture and interventions to existing buildings, heritage sites and, urban design. With the advent of real-time rendering and live streaming of Virtual Reality environments it is possible to interactively evaluate project vision by non VR experts. This paper discusses innovative developments on VR, and in particular applications from video-gaming technologies VR online publishing and live VR broadcasting. The paper reviews medium and evaluates software tools. The paper discuses on potential frameworks for further empirical research within the domain of environmental psychology. Five design projects are described, software attribute tables prepared and qualitative feedback presented. Although the paper mainly focuses on technology it concludes with evaluating empirical studies on people-environment and design utilising emerging VR authoring and broadcasting tools.

Keywords
Design, Live Streaming, People-Environment Studies, Architecture Visualisation

1 Introduction

Engaging with Virtual Reality in architecture and urban planning provides new and exciting opportunities as the technology has matured and will continue evolving. Much of the VR development has been propelled by video-gaming as it is one of the fastest growing industries, partly exacerbated by lockdowns during global pandemics in 2020 and 2021. Because of this, VR adoption is taking place at a rapid pace and both, cultural and technical barriers will continue to diminish bringing tangible and direct benefits to niche industries such as architecture and planning. With mass adoption also comes a drop in cost and improvements with user interface (UI), no codding or programming is now required to creating professional VR environments neither. Architects, designers, and urban designers can now author and broadcast virtual scenarios even if they are not 3D modelling experts. Licencing for authoring and publishing VR environments is now simple.

VR real-time stands for the ability to render buildings and design on-the-go rather than post processing. Cloud computing is unlocking the potential to generating high resolution and photorealistic VR renders taking away the problem of internal workstation CPU and RAM. Cloud computing allows for image processing non-dependent on the workstation. In the case of real-time VR is now possible to broadcast and share VR environments accessible on relatively small devices either, desktops and laptops with the capability to also connect VR glasses or a headset.

A user-friendly interface for VR postproduction and publishing is certainly a breakthrough for rapid adoption. Although much of the 3D modelling and BIM authoring tools require C++ and visual programming such as Python with parametric design tools such as Dynamo™ for Revit™ and

Grasshopper™ for Rhino™, Virtual Reality software has evolved in parallel mainly from videogaming technology. An example is TwinMotion™ that runs at the back of Unreal™ gaming engine by Epic™ games. TwinMotion™ is accessible with a small installation file and friendly user interface, it is also reasonable priced. Full installation of Unreal™ gaming software is optional.

On the affordability side, VR software is no longer acquired through expensive licencing for ownership but rather on a subscription and usage basis, making it affordable s small firms and even start-ups. Accessing the software which also runs on standard workstations (commonly used in architectural firms) provides the right scaffolding for the technology uptake. High-end graphic cards, CPUs and HD monitors and peripherals such as the 3D headset is optional but recommended once the practice is conversant with the technology. This scenario also enables start-ups and freelance practitioners to make use of VR without an upfront monetary burden. Up to recently only large firms could afford to have the VR experts inhouse or would outsource it to specialist. The argument here is that VR should be an integral part of the design process and integral to engaging with clients allowing at time participatory design to take place. On the other end of the spectrum, architects employed by large firms are now more likely to get approval to have VR software installed in the workstations making it part of the design workflow i.e., integrating with the standard BIM toolkit.

On the receiving end (such as a client accessing the VR scene for instance) technology has evolved to a point that once the VR has been published there in no need to have dedicated software nor specialised viewer or software installed but the VR can be accessed via a web browser, video streaming channel such as Youtube™ or social media channel such as Facebook™. It is also possible to access VR from various peripherals, from standard monitors and projectors for 360degree viewing to full immersive experience with headsets such as Oculus-Quest2™.

VR interoperability and post-production can be streamlined by operating on the cloud and accessing from various devices. Proprietary software vendors are increasingly aware of the importance of interoperability as well. This means that VR files can be accessed by various BIM and VR software applications. Saying that, software developers continue aiming to stablish captive markets and user-group loyalty. Achieving open standards for interoperability across software is still an issue to solve in the prevailing proprietary climate. This has been much discussed over the years (Aranda-Mena and Wakefield 2006). However, open standards for file exchange are available and increasingly in use. Virtual Reality with Twin Motion™ is possible with file exchanges via Datasmith protocol.

Scalability is another technological improvement in the VR space. Mobile computing is rapidly evolving, through smart phones, tablets, and laptops, and some of the hybrids such as phablets and laptops with touchscreens. This means that if the VR project started with designing 3D space for example in Formit™, as an early project concept *on-the-go*, same file can now be accessed from a workstation with a robust version of the same software application or imported into another application for further developed. File synchronisation (sync.) is often available. *Roundtrip* is when the native file has been altered by a third-party plugin off main BIM authoring application e.g., the main model is updated every time there is a calculation or update by the plug-in application.

The real-virtual continuum. We can refer to this continuum as an ongoing link between the virtual and the analogue world. In times of imposed social isolation and lock-down it has become clear that technology is a medium that allow us to operate, not as a substitute to our real physical world but as an addition to it and not only as ‘augmented reality’. Although virtual and immersive technologies are still in their infancy, they have now reached a level of maturity providing a gentle learning curve. We live in times when the benefit of adopting VR seem clear, and if not, at least piloting and playing with the technology, same technology being propelled by videogaming, should be a must in architecture practice. Afterall, this is already a practice gamechanger which will continue to evolve.

2 Architecture VR Live

Architecture VR Live is here defined as:

> *'[the] ability of broadcasting 3D Virtual Environments of building design and urban planning at conceptual, development and project review meeting stages via an internet video-streaming channel merging both, a (1) virtual environment production (2) synchronously' accessible real-time by a (3) co-located and inter-office group. Just in the same way a music band might be performing live to a face-to-face and online audience.*

This represents a breakthrough as the speed of rendering buildings and settings has increased. The *on-the-fly* ability to render and displaying virtual scenarios in motion (both as navigating through the space and as dynamic objects within it) is now possible through faster clod-based processing making. Making interactions with client, other designers, and stakeholders more fluid and enabled rather than obstructed by the technology where synchronous face-to-face and online design meetings and project reviews can take place.

Accessing VR can be through web browsers projecting on screens or peripherals such as VR glasses or headsets, there is still room for better studying the psychology of *(i) interactive* and *(ii) iterative* design collaborating options, either collocated vs. interoffice, synchronous vs. a synchronous. This presents an opportunity to scale up the design from concept into schematic bringing participatory design opportunities for instance. For example, a design practice based in Melbourne, Australia could import a Building Information Model (BIM) from a town council or planning office in Mexico sharing a basic 3D massing model in any standard file such as a Rhino™ import into TwinMotion for VR via Datasmith™ protocol for data exchange. In the case of Rhino-TwinMotion, all work can be synchronised with plug-in (also available for other commercial BIM applications such as Revit, 3DsMax, Rikcad, Archicad and SketchUpPro) which allows roundtrip updates from either the BIM or the VR ends.

The 3D building asset can also be imported into a gaming engine such as Unity™ or Unreal™ by Epic Games™ with high-end programming capabilities if need for further post-production for presentations under various formats such as high-resolution PNG images to, 360-degree navigable panoramas, to true VR scenes. Export of projects has also the ability to creating 4D time/process simulation for project construction or life-cycle simulation, for example in the case of looking a project development stages or lifecycle landscaping.

A business scenario would be a small practice further developing an early schematic design (even if hand-drawing) into a 3D model for further photorealistic visualisation including other entourage such as landscaping, people, and vehicles. This links to earlier work carried out by Heintz and Aranda-Mena (2012). Twin Motion™ has a plugin option from Quixel™ as a material, render and object library of high-resolution scans of real-world materials and objects including from terrain, vegetation, to vehicles, people and even light conditions and even light conditions and weather data (Quixel reported an object library of 15,907 digital assets when this paper was written.

3 Authoring and broadcasting VR

Here we introduce two stages to achieve a VR Live session, one is the authoring or the 3D environment and secondly to publish it. Both stages could be either sequential or synchronous depending on the intent i.e. creating a VR and then publishing it online for access to the team or co-creating the VR as part of concept development workshops, participatory design sessions or project review for instance. Although participatory design and immersive environments have been widely discussed in academic journals for some 30 years (Aranda-Mena et al. 2004) the technology is finally able to support the design process and not the other way around. Still, perception, communication, and people-environment applied studies in this area are still much needed though.

3.1 Authoring VR:

The base 3D preparation of a VR environment is carried out (authored) in BIM tools and then imported into VR software tool for post-production. BIM applications that are interoperable with VR platforms include Rhino, Archicad, Revit, Vector Works, 3DsMax, and SketchUp Pro amongst other well-established and commercially available products. During the preparation of this paper two master classes created 3D buildings utilising the above tools and some of the discussed attributes are presented here below:

Table 1: BIM for VR: 3D authoring tools

Interoperability and functional attributes of 5 BIM for VR 3D authoring tools across various protocols for file exchange. From basic 'save as:' to the export-import file exchange option to full synchronicity across tools and applications via an app.	Rhino	Formit	Revit	Archicad	Sketchup
Plug-in for parametric design. Full Grasshopper or Dynamo integration (***). Note that integration with Dynamo only takes place while running on the standalone Formit Pro version. on a laptop or desktop. Archicad and SketchUp Pro have some level of parametric design option that are built into the standalone applications.	***	***	***	*	*
Plug-in for Virtual Reality. Either via 3D file export (*) Datasmith exporter (**) or full data exchange integration and synchronisation (***).	***	*	**	**	*
Plug-in for energy analyses. Effectiveness with energy analyses tools such as Sefaira, Insight (Green Building Studio) or Grasshopper (Honeybee and Ladybug). All run with e+ data in .epw files (Energy Plus Weather format).	***	**	***	**	**
Flexibility for geometric modelling: Free-from design which is highly flexible (***) to a rigid or more constrained model (*).	***	***	*	*	***
Object and building data capture: Rich-data capture of building components (***) - only geometric and spatial information (*).	*	*	***	***	**
BIM file exchange: large and reliable import/export range (***) limited and faulty import/export range (*).	***	**	*	**	***
Market penetration (Australian context). Dominant product (***), established product (**) and emerging product (*).	***	*	***	**	**

The above table 1 indicates the level of interoperability and synchronicity for various commercially available BIM authoring applications. The list/descriptions aim at illustrating key areas of interest rather than being exhaustive and determinant. Today it is possible to produce Virtual Reality easily and sharing it online a standard desktop PC. This provides new opportunities for architects and built-environment professionals. Information exchange, user interface, file size, and the ability to modify, share and access VR projects on the cloud are amongst the main incentives for business uptake. File combability and interoperability is becoming seamless, and, in many cases, available plug-in ensure synchronicity between 3D authoring, analytical and VR tools. Current developments provide new opportunities for architects, planners and their clients and project stakeholders.

3.2 VR Broadcast

Once VR post-production is completed, preparation for broadcasting and model sharing can be organised in various ways. In this case we will discuss two effective formats: Twin Motion™ Cloud hosting and Open Broadcast Studio™ (OBS) which is written in C, C++, and Qt for User Interface (UI), the initial version appeared in 2012 and the latest version 27 (OBS 2021).

The Twin Motion™ Viewer offers a cloud-base application with a service to host VR environments which can also be easily accessible on the web. This provides an easy of sharing and accessible environment even for non-visualisation experts. On the receiver end all is required is a web browser allowing a client or non-expert stakeholder to have access to the VR scenario and can interact with its weather through a desktop, laptop, tablet, or even smart phone. This opens opportunities for engagement, feedback and iteration not seen before.
A second option is to use OBS in addition, or as a substitute, to Twin Motion™ cloud viewer. OBS is an opensource software that works on Windows™ or Apple™ operating systems. OBS also originated from the videogaming community some 10 years ago. OBS allows to broadcast custom or tailored scenes creating a 'Virtual' camera which can easily be set as the default camera for any broadcast application such as YouTube™, Twitch™ or Face Book™. It can also work as the default (virtual) camera for any teleconferencing applications such as Zoom™, MS Teams™, WebEx™, Skype™ or similar.
OBS enables an architect or presenter to switch in between scenes while on face-to-face and online live meetings presenting thus various project with a *high-level of control on views and formats*. The broadcasting also offers options for comments and interaction with client. OBS scenes setup in combination with real-time VR offer what we refer here as VR Live.
A worked example on setting up scenes say, on a design review meeting with client include:

- **Welcome Scene:** webcam 1 presenter; pre-recorded video of project/model. Also, with sound and voice mixer. OBS has filters and VST plug-in for sound and voice-over editing.
- **Main Meeting Scene:** webcam 1 presenter; webcam 2 physical model or material library; webcam 3 aux It could be a remote camera or link with client or builder on site, for example. Note, webcam 3 is in addition to the standard webcam view available within any of the standard teleconference apps).
- **Live VR Project Scene:** webcam 1 presenter; share Twin Motion™ application; share web browser and options to activate/hide web cameras 2 and 3.
- **Whiteboard Scene:** webcams, 1, 2, 3. and a view of shared virtual board such as Miro™, Canva™ or MS OneNote™. Hear each meeting participant can login and notate on the virtual whiteboard by typing on postITs or directly sketching notations using a stylus if joining via a table or touch screen laptop.

OBS scenes and sound dashboards: Transitioning scenes is important, OBS has the facility to set a full screen with preview of various scenes before they go *'on air'*. If using a touchscreen PC, the presenter can simply touch the pre-view window to switch across scenes, if not, a simple point and mouse click can do the trick, as a third option, it is easy to set a remote interface using a smart phone or tablet with an app such as Touch Portal™, this would provide a smart way to include various in-situ meetings participants.
Audio: sound quality in design reviews and presentations is often overviewed, especially when the focus is generally so strong on aesthetic outcomes. Sound clarity is very important, and sound quality can really enhance a virtual experience. The author explored and tested many software tools to improve sound quality while Live VR meetings or for pre-recorded VR scenes (sound files can be easily embedded in VR scenes). Here three tools that are open source. See links in reference list.
VoiceMeter: (VB-Virtual Mixer: Banana version). This is a virtual standalone audio mixer and synthesiser of all sound inputs and outputs. It is a highly convenient tool that enables a great level of control on the input and output of sound sources and the mixing of them. There are 5 input channels (three for hardware and two virtual) and two output channels. For example, a typical setup would include an external microphone, headphones microphone and perhaps a web-cam mic. Then, there are to virtual inputs, once would be a PC as playback device and finally a virtual channel which can be any dedicated application, for example only sounds from YouTube. In this way you can mute any channel or mix sounds during the presentation. There can also be pre-set controls.

VST plug-in for OBS: (Virtual Audio Technology): is a virtual synthesiser and an excellent tool to improve sound quality, it can work as standalone (Reaper) or as a plug-in software app within OBS. It provides a set of 9 sound dashboard that range from sound filters to cut-off background noise, equalizer, noise gate, compressor, expander, gain, and other tools to boost sound for pod and broadcasting. Although a great tool, it takes time to calibrate and pre-set filters, this is because every voice is different, and some testing is required. Also, the environment surrounding the presenter also has an impact, if setting up the filter to block background noise. One filter that was found very useful is the noise-cancelling filter. To set this you must create a *noise profile* of the room, save it, and the filter will subtract such noise profile from the presenter voice. So, for example if the noise profile includes the sounds of typing a noisy keyboard, when the filter is activated it cuts off those sounds. The more background noise to eliminate the more artificial (robot-like) the voice of the presenter sounds.
Nvidia™ Finally, the most effective filter to block background noise is the NVIDIA™, which requires the PC to have an GTX™ Nvidia™ graphic card for noise removal. Which means that to instal the application the GTX graphics card must be installed. There is an option for installing this as plug-in within OBS. Nvidia is the most effective application found for sound boos and noise suppression as the software uses Artificial Intelligence to process the sound ie. identifying your voice and filtering what is what is not yours. Nvidia claims that even a vacuum-cleaner can fade away!
The ability to inhabit designs and spaces as fully immersive VR experience without even having the software installed in a mobile phone or laptop is certainly a game-changes. It is now possible to livestream VR projects and host them on the cloud. This significantly brings new opportunities for clients and their architects, whether meeting remotely or face-to-face, ultimately of benefit to improving design decisions, design outcomes and thus better shaping our *real* environment!

4 VR Live: Case projects

This section presents five scenarios to pilot-test VR in architecture, urban design, and workplace research. The design philosophy of the G-Lab architecture studio is beyond the scope of this paper however, it has been described in Aranda-Mena (2016, 2017).

4.1 Live VR_01 UNESCO heritage sites

This project is currently being prepared as a complete paper submission for the 49th CIB_W78 conference on Information Technology for Construction, Melbourne June 2022. The work is done by the author in collaboration with the UNESCO Chair at Politecnico di Milano. The studio has undertaken projects in Europe, Northern Africa, the Middle East, Latino America, Asia, and Australia and currently preparing projects in Rhino for design interventions, Grasshopper™ (GH) for energy and economic appraisal and TwinMotion™ for VR immersive experience design evaluation. A list of world heritage sites ranging from Villa Adriana near Rome; to Petra in Jordan; to Tell Mozan in Syria to Milano, Bologna, Verona and Mantova in northern Italy (Orbit Inova, 2021).

4.2 Live VR_02 Urban scale: Designing a 20-minute city competition

The fist VR scenario is an urban project proposal in Melbourne, Australia. It is a competition entry by the G-Lab to regenerate a northern suburb known as Croydon, after 1961 it was set as an independent shire and in 1971 proclaimed a city, with a planning principle as a ‘green new town’. Half a century later Croydon is lacking charm and identity. An open competition requested the rethinking of an area around Croydon South’s shopping street. The G-Lab project proposal extended the original scope of the project generating a *’green boulevard’* along a creek connecting the South with Croydon Civic Centre and the train station (see central image in Figure 1). The green boulevard is expected to increase pedestrian and cycling traffic as to reduce car dependency. By connecting various *'anchor-elements'* through urban interventions such as landscaping, lighting, art, and street furniture. This is expected to re-energise Croydon neighbourhood with increased liability and vibrancy tapping into recreational activities, sports, people movement, arts, and events. From energy and sustainability by capturing solar and kinetic energy to be self-sufficient for public and street lighting needs. 15 individual designs and buildings were all modelled in BIM (e.g., in Revit™, Rhino™, Archicad™, Formit™ and SketchUp Pro™) and Insight™, Sefaira™ and Grasshopper™ Honeybee™ and Ladybug™ for comfort, lighting and sustainability energy analyses.

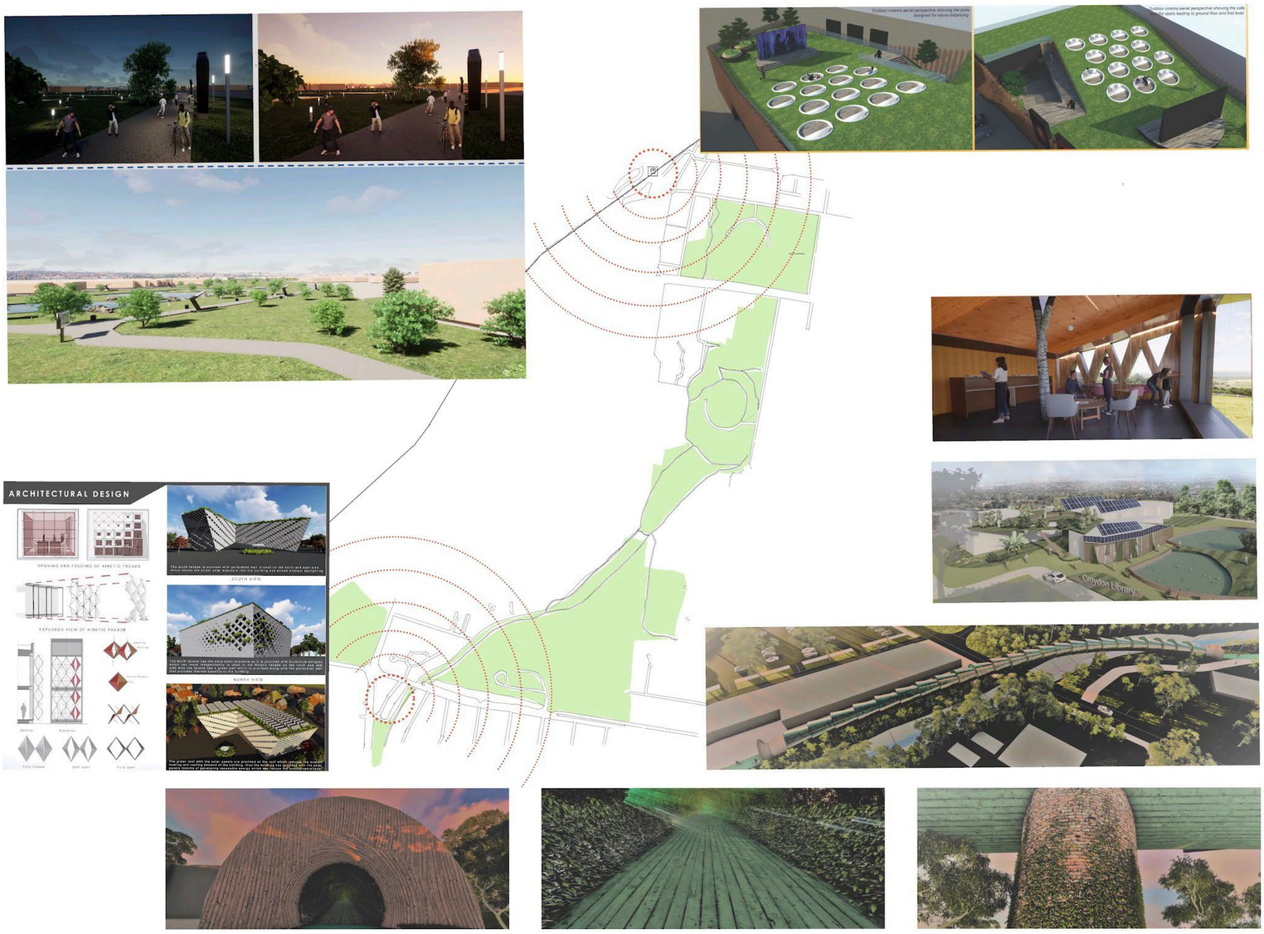

Figure 1. Screenshots of Virtual Reality project developed in TwinMotion™ with dynamic renders

The above Figure 1 is a short selection of individual designs prepared for 15 sites across the location. Site specific designs are used to integrate into the surrounding environment and increasing pedestrian and cycling activity. Engaging with *biophilic design* (Hayles and Aranda-Mena 20218) in the case of the 'Green Promenade'. The user centred design aims to connect people with the open spaces, where they work, live and play, by introducing higher density living and incorporating walkable, bikeable, bus and rail mobility linking Croydon Civic Centre and rail station with Croydon South shopping strip. All 15 individual building projects were incorporated via Twin Motion™ thus creating a Virtual Reality master plan. A summary of identified benefits of Live VR and real-time rendering include (starting from top left corner of the above image and moving clockwise):

- Ability to design public lighting and show changes at various times of the day and seasons of the year. There is no need to wait lengthy time to see the effects of light grid design. Here it is also possible to effectively identify risk areas (black spots) such as day, dusk, and night-time.
- Design of green roofs. In this case a rooftop cinema. Realtime rendering validating panoptic (horizontal angle) and isoptic (vertical angle) field of view from any seating position.

- Maximising views to surroundings from within government and community buildings. It is also possible to change time of day and weather conditions and see the impact to the indoor space. Rendering done real-time and connected with client and community Live.
- Landscape study of the main library with green surroundings, lake, and water features. This is a flood-prone area, and it is possible to model on-the-fly water level across rain and dray season bringing elements of *water-sensitive urban design*. Same image shows *photovoltaic* design for library roof. Twin Motion provided elements of solar incidence but more importantly, a way to view the impact for PV panels optimum tilt (to maximise sun exposure) on the overall design as seen from various angles.
- Green Spine foot and cycling bridge built recycled materials, natural and sustainable materials. The bridge has an element of element and protection which also isolate from views into the busy traffic road underneath. Both, field of view and acoustic ques, can be tested within Twin Motion™ to maximise outcome from user perspective and not only its aesthetic qualities from the road and other advantage viewpoints. The three bottom images are detailed views of the bridge including support, path and access point if seen from right to left.
- The last image shows the architectural design for a civic building and office spaces. The proposal incorporates kinetic design and Twin Motion can simulate various openings of the façade panels according to openness and closure user requirements or as activated by weather sensors. This will be further discussed under Live VR_03 M: Kinetic Façade.

The benefit of Twin Motion™ includes a tool to integrate all design files into a single VR file. The Twin Motion™ viewer allowed the team to see their designs into the larger urban context. It also allowed the ability to model people, cycling and train Motion™ under various frequency (speed of movement) and density conditions e.g., distance between pedestrian or number vehicles on the road. Variables could be modified according to time of the day, peak hours, or day of the week. Finally, it allowed better understanding of the interaction of buildings with greenery and urban furniture allowing the design team to explore variables, in particular long-term time variables. For example, the relationship of the green spine, roads, and property development. The ultimate ambition of this project was to create a 15minute city in which residents could operate their daily activities within 15minute walk – and with this contributing to place-making and quality of life of the residents.

4.3 Live VR_03 Civic Scale: Designing a Railway Station

In a recent study the author applied VR Twin Motion™ on a study for biophilic design as part of a Master Thesis supervision (Byrnes 2021). Biophilic design considerations for a train station in Melbourne, Australia in which real-time VR presented *'transitionary'* greenery scenes in a way that it was possibly to evaluate future outcomes of the landscaping across seasons in the year and vegetation growth in a 30-year life cycle. Live VR can provide realistic understanding of how greening and vegetation changes over seasons, time of the day and climate conditions, more importantly is the positioning and arrangement of vegetation in new or existing environments which is a new development only possible with real-time rendering. This presents the potential not only to show clients the outcome but the impact of design decisions over the life cycle of the project and the effect that this might have on evaluating project success and futureproofing. There is also potential to see the impact of designing with evergreen vegetation versus deciduous vegetation, both are equally good options but deciding factors are better placed to project conditions and site specificity. For instance, evergreen is good, but it might block much needed winter sun penetration. Whereas deciduous can let plenty of winter sun into the building but it would not particularly contribute to improving the visual or aesthetic aspect of a building thus the architecture takes then fore ground and thus important to evaluate via VR scenarios. Lastly, Twin Motion™ provides a realistic lighting and shading rendering in the VR scenes and this is important as evaluation on occupant comfort, daylight, glare, thermal comfort and even views i.e., to understand the impact of vegetation from the inside-out of the building across time and seasons.

If comparing with rendering tools such as V-ray™, 3DsMax™ or Maya™, one often need to wait hours to see and evaluate the render i.e., a single static rendered image. Lumion™ rendering is like Twin Motion™ but without the benefit of connecting directly with a gaming engine such as Unreal™ for further and more powerful postproduction process for high-end visualisation, interface, and interactivity, albeit utilising more specialised visual programming and scripting in C++.

4.4 Live VR_04 Building scale - Designing a Kinetic Façade System

Facades and building envelop continue to shape the way humans interact with the environment, not only in terms of the aesthetic look of buildings but also to improve interior comfort and energy optimisation. Kinetic designs require modelling of materials and structures and their mechatronic motion (Burry et al. 2013). In this way real-time VR allows motion rather than the traditional static rendering tools. Applications such as Unity™, Unreal™, Lumion™ and Twin Motion™ provide an effective way to simulate movement and exploration in the environment in first person through a VR experience. Movement of kinetic façade system can be set and activated for opening and closing. The avatar in the VR space can operate the façade shutters or any operatable element and then investigate the resulting level of shading. An element with kinetic that could be incorporated are Photovoltaic panels thus creating a more dynamic Building Integrated Photovoltaic (BIPV) (Aranda-Mena and Fong 2020). In commercial projects, façade panels and elements are modelled physically including (i) visual and (ii) performance muck ups costing an average of $70K AUD each time. Realtime VR can provide a cost-effective way to run early prototyping and simulations with the potential to significantly improve design and project outcomes.

4.5 Live VR_05 Interior Design Scale: Individual Workspaces for Organisations

Office and workspaces have been turned upside-down since the start of the pandemic in early 2020. As the working from home is here to stay, many office spaces are engaging with hybrid *modus operandus* or ways of working for their staff. In this way the design of workplace and office environments has become less tangible and more fragmented (Finch and Aranda-Mena 2021). Places like Melbourne Australia, the city with the world record for the longest with hard lockdown of over 250 days since March 2020, after Buenos Aires. Melbourne now provides a good example how workplace could have re-set for good. In other words, real-time VR can provide and excellent tool to identify effective workplace design for individuals rather than teams or organisations. In other words, turning the up to recent one size fits all model into a more humane bespoke model in which employees can design their workspaces according to their working preferences and styles. The author of the paper is trailing VR to reflect personal needs and preferences to identify workspaces within and outside the employee premises. For example, what would be possible to do for redesigning the office space and the home office.

Also, using VR in combination with immersive photography to create a virtual library of new and existing spaces that could be available to employees such as libraries, co-working spaces and even parks and coffee places that would have a level of support for office workers. Organisations are also looking to provide more options on satellite offices often close to home. This last section closes the loop of the 15-minute city presented above. Living, working, and playing within 15-minuest walk from home (Aranda-Mena 2019). This model is also more sustainable, reducing the commute time and stress that goes with it. The environmental needs and preferences can easily be tested by the interior architect and ergonomist through the VR library, variations of it or new designs from afresh. This obviously can also be an area where practice and academic research overlaps thus contributing to our understanding of motivation, wellbeing and thriving individuals.

Finally, individual clients and organisations often ignore the value of enhancing workspace-aesthetics with art and nature – which now can be real-time rendered in tools such as Twin Motion™ and designs trailed and tested with increased degrees for confidence. However, scientific studies reveal that both factors significantly contribute to employee well-being and measurement of occupancy satisfaction. On a neurological level emotional response to aesthetic dimension arise by reading from all five senses. Stimulating positive emotions at work are difficult to measure, still we know they exist (or not). Most organisations focus on measuring change and output, however, looking a design intervention with VR can provide a more accurate understanding of the person and the environment around him or her. As the instrumentality of the workspace i.e., what is needed to 'get the job done' prevails and the focus is on 'doing' rather than on being or feeling.

5 Conclusions and Further Research

This paper has introduced and positioned VR technologies within the architecture and planning domain. Arguing for an add-value practice and business propositions because of technological maturity which is now accessible to a wide market from small start-ups to corporate design firms. The above five case sites demonstrate VR applications on various project typologies. Strengths and weaknesses are drawn and have set the scene for follow up studies and publications. Thirdly, in this we provide a hands-on guidance to kick-start a VR project takin into account both, authoring of VR and broadcasting VR, references with further examples as provided. Finally, a definition of 'VR Live for Architecture' has been elaborated. Future studies on the emerging human experience, especially on user-centred design approach with recommendations for architects and planners on proving professional practice will be further developed.

This paper has re-visited Virtual Reality technologies with a fresh eye, looking into current development of the technology and applications for the practice of architecture and people-environment research. A descriptive and procedural section accounted for the setup of VR Live via broadcasting channels in VR format such as YouTube. The technical section also guided on the set up of Open Broadcast Studio (OBS) in combination with Twin Motion™ (TM). The following table summarises identified attributes across design scenarios and technological capability. This can assist researchers, architects, urban landscape, and interior designers to better set up and stage their virtual environments and their research design.

Table 2 VR Opportunity versus Project type: a summary of case projects and identified attributes

Identified Opportunity	Live VR_01 UNESCO sites	Live VR_02 Urban Scale	Live VR_03 Civic Scale	Live VR_04 Building Scale	LiveVR_05: Scale Building Interiors
Greenery motion	*	***	***	**	***
People motion	*	***	***	**	***
Traffic motion	*	***	***	*	-
Site staged change	***	***	***	*	*
Soundscape/noise	*	*	**	**	***
Dynamic light/shade	*	**	**	**	***
Dynamic glare	-	-	-	**	***
Weather/climate	***	***	***	**	*
Rainwater motion	***	***	***	*	-

From the above Table 2 indicates how VR (via Twin Motion™) was used both, as the *repository* for each building and as the tool to complete the urban design, integrating thus all buildings into a site more commonly referred as the master plan. Proposed new buildings and upgrades to master plans include: a housing states, a public administration building, UNESCO heritage interventions, planning, and urban landscaping projects have been summarised and synthesised according to scale/opportunity relationship.

A qualitative study of the above Table 2 and survey data is to be presented at the 49th CIB_W78 conference on Information Technology for Construction, Melbourne June 2022. On the technological end, if looking at Rogers' Diffusion of Innovation Theory and Moore's Chasm theory it can be concluded that VR technologies and uptake have move onto a safe and stable for adoption. Full empirical research on business drivers for VR industry uptake will be carried out, now is clear that a *plato* has been reached like that of BIM uptake in business at the turn of the 21st Century (Aranda-Mena et al. 2006), in the VR space uptake might be more rapidly because of rapid of the wider market videogaming. Other enablers such as wider broadband Internet availability and social media move into VR with Meta™ from Facebook™ for instance. Meta (of Metaverse) is FB's newest company brand introduced in October 2021. This flags the expectation that VR will continue evolving in the same trajectory described in this paper. Future stages of this work will delve into the psychological response such as (1) human-computer interaction (2) people-environment studies and (3) decision-making all within Kelly's research framework of Personal Construct Psychology.

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Developing Bluetooth communication technologies for safer construction sites: Experiences and learnings

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Abstract
The construction industry is one of the most dangerous industries when it comes to safety and situations involving collisions between vehicles and workers are often fatal. Site activities are carried out simultaneously by skilled workers and machine operators, which makes communication between these groups crucial. Based on a single case study, the aims of this paper are to investigate: (i) problems related to communication on construction sites and (ii) the usefulness of Bluetooth headset technology to improve communication. In the first research phase, three semi-structured interviews revealed problems related to communication. Respondents identified improvement areas such as sound isolation in vehicles, making it difficult to hear, and problems with using sign language when it is dark or too sunny. Working together with the same person on a regular basis improves communication as well as safety and productivity, and interviewees suggested that inexperienced personnel should be mixed in groups with more experienced personnel, which can help them to avoid injuries and learn safer practices. In the second research phase, Bluetooth headsets were introduced to improve communication between different groups. Data was collected through five rounds of mini questionnaires with construction site personnel. Feedback from each survey was used to improve the usefulness of the Bluetooth headsets. Analysing patterns from respondents' suggestions, showed that they first complained about the fit and comfort of the headsets, followed by noise isolation, frequency and other additional functions of the headsets. The possibility to add warning signals enhance the usefulness of Bluetooth headsets, e.g. by increasing the situational awareness and reducing cognitive load of construction workers, making workers more productive while also helping to avoid injuries.
Keywords
Bluetooth headsets, communication technologies, construction sites, HSE

1 Introduction

The construction industry is one of the most dangerous industries in Sweden. According to the Arbetsmiljöverket's statistics, there were 3680 injuries/year (11 injuries/1000 employed) between 2014 and 2019 in the construction industry, which has the second highest number of injuries reported, right after manufacturing industry (Arbetsmiljöverket, 2021). For the same period, the construction industry also has the highest number of deaths, followed by transportation industry. According to a recent report by Samuelsson (2019), the cause of injuries among the private companies were damage from tools (18%), physical movement with physical overload (17%), falls at the same level (stumbling) (13%) and fall from height (11%). Although vehicle and machine related injuries are reported as only 12% of the total injuries, 206 out of 434 (47%) deaths on construction sites in Sweden between 2010 and 2019 were due to lost control of vehicles and machines, being by far the main reason of deaths on construction sites (Arbetsmiljöverket, 2019).

At construction sites, different groups of professionals including skilled workers and machine operators work simultaneously and, communication between heavy vehicle operators, crane operators and other workers is crucial for safer construction sites (Zekavat and Bernold, 2014, Gürcanlı *et al.*, 2015, Sanni-Anibire *et al.*, 2020). A good communication between different groups of workers is essential especially in smaller construction sites with less space and high time pressure for not only safer construction sites, but also for not retarding their productivity.

Different methods are used on construction sites for communication including walkie-talkies, verbal communication, a mix of verbal communication and hand-arm gestures and only hand-arm gestures (Bedi *et al.*, 2021), however all these methods have their limitations. Therefore, the aim of this paper is to investigate: (i) problems related to communication on construction sites and (ii) the usefulness of Bluetooth headset technology to improve communication. Based on semi-structured interviews and questionnaires administered to construction site personnel, problems associated with communication on construction sites were identified and usefulness of Bluetooth headsets were investigated.

In this paper, difficulties related to verbal communication and hand signals are reported as well as limitations of the Bluetooth headset technologies and suggestions for improvement. The paper is based on a single case study from Sweden, meaning that while applying the findings of the study, the context of the case should be considered. However, having a single case study allowed us to investigate different functions of Bluetooth headsets for the same sample, during the course of production. This is one of the rare investigations where a safety technology is applied at a real construction site where different functions of the technology were assessed. The paper is useful for construction companies who are willing to apply Bluetooth headsets as well as for the safety technology companies to improve their products based on the suggestions reported from the workers.

2 Problems with on-site communication channels

Of the many ways to communicate at site, verbal communication is the most common. However, construction sites are often noisy and congested, which makes it difficult to use verbal communication. Hand signals are not influenced by noise and are commonly used to inform heavy vehicle and crane operators (Mansoor *et al.*, 2020). However, while using hand signals, information is sometimes transmitted through several people. In case a participant makes an error of copying the information such as interpreting it wrong, serious accidents can happen (Fang *et al.*, 2016). Moreover, physical distance between workers or high levels of background noise can harm these forms of communications (Haslam *et al.*, 2005).

Two-way radio communication is one of the approaches involving a technology and is suggested by various authors in past studies (Haslam *et al.*, 2005, Bedi *et al.*, 2021). Two-way radio communication requires a dedicated channel to talk and communication between operator and signalman being maintained at all times. Similar to verbal communication, in case there is noise, the communication will be disrupted. Moreover, there can be technical problems as well (Mansoor *et al.*, 2020). Tam and Fung (2011) identify two problems with two-way radio communication: (i) various workers using the same frequency which increases risk of interruption and misunderstanding and (ii) one of the two hands of workers being occupied with using the radio. Moreover, it was revealed that inexperienced workers have troubles to fully understand the communication methods. Instead of two-way radio communication, wearable Bluetooth communications can be used to overcome these challenges.

3 Research Methodology

In this study, an infrastructure project was used as a single case study to collect data. The construction site is located in city centre and suffers from tight physical space. Single case studies are useful for detailed explanations of why particular outcomes occur (Dubois and Araujo, 2007) and they provide rich, empirical and contemporary descriptions from the investigation of a particular phenomenon (Eisenhardt and Graebner, 2007), in this case application of Bluetooth headsets.

The data from the case was collected in two different ways. To reveal problems related to communication on construction sites, three semi-structured interviews were carried out before the implementation of Bluetooth headsets technology. A crane operator, a machine operator and a skilled worker were interviewed and each interview lasted around 30 minutes in average and they were all transcribed. In order to investigate the usefulness of Bluetooth headsets, mini questionnaires were administered to site personnel, in five rounds. The first questionnaire was administered before the technology was introduced and was answered by 15 workers. Feedback from each questionnaire was used to make the Bluetooth headsets more useful, leading to four rounds of improvements followed by a new survey. Number of completed questionnaires were 14 in the second round, 10 in the third round, 7 in the fourth round and 11 in the last round. Considering the number of respondents, the questionnaire analysis included only reporting of mean values.

4 Findings and Discussion

In this section, first on-site communication problems are described, based on the interviews and then test results of the Bluetooth headsets are presented.

4.1 On-site communication problems

In overall, interviewees were less worried about injuring themselves. Crane and machine operators were mainly afraid of injuring others which can be due to pinching/squeezing someone with machine or dropping something on them when they work under a bucket. The interviewees named several reasons that influence safety of construction site personnel when they work in collaboration with machine and crane operators, and these can be categorised as factors limiting vision of workers and limiting verbal communication.

Weather conditions such as very windy and rainy days is one of the factors reducing vision of the workers. Sunshine is not a problem for skilled workers since they wear protective eyeglasses which act like sunglasses. However, for machine operators, if the window of the machine is scratched or dirty and if there is sunshine, then their vision is limited badly. Moreover, while working in darker areas, vehicles turn on the lights which reduces vision of other personnel. Sign language is used for crane operations but when it gets darker or too sunny, it becomes a problem as well. These can be added to the list of factors identified by Fang *et al.* (2016).

When it comes to verbal communication, high levels of background noise reduce quality of this form of communication heavily (Haslam *et al.*, 2005). According to the interviewees, verbal communication is limited while working in environments like tunnels due to noise coming from the machines and echoes. In addition, machines are often well sound isolated which makes it very difficult to hear when someone shouts from outside. Bad planning and changes in plans make it difficult to collaborate. Daily plans are very important so that big machines can work far from each other, and problems related limited space can be avoided.

The interviewees mentioned that it is easier to communicate when they work together for a while, especially when a skilled worker works together with a machine operator. Experienced skilled workers tend to work safer, and the interviewees were claiming that inexperienced skilled workers often end up in wrong places or situations. Tam and Fung (2011) revealed that inexperienced workers also have troubles to fully understand the communication methods. Although working together with the same person improves their communication as well as safety and productivity of the task, interviewees were suggesting that inexperienced personnel to be mixed in a group of more experienced personnel, which can help them to avoid injuries and to learn safer practices.

4.2 Implementation of Bluetooth headsets

In the case project, Bluetooth headsets were tested in four rounds and in each round, adjustments were made for the headsets (see Table 1 for details). During the assessment, respondents were asked about their channels of communication with colleagues on the site and alternatives included verbal communication without headsets, telephone via Bluetooth in headsets, hand gestures, two-way radio and headsets with level dependent function. In round 0, before the implementation of Bluetooth headsets, favourite communication method of the respondents was reported as verbal communication without headsets. In general, the respondents were least satisfied with the communication quality with truck drivers (2.8 out of 5), followed by excavator operators (3.3). They were also not satisfied with their current headsets (2.8). Their feeling of safety for three conditions associated with large vehicles was neutral. Respondents had some suggestions for improvement including tighter fit of headsets around the ear, communication without requiring calling the person, being able to talk to people without requiring to take-off the headsets and two-way radio.

Round 1 is when simple Bluetooth headsets were implemented in the construction site and respondents' favourite method of communication switched from verbal communication to telephone via Bluetooth. Compared to the previous round, respondents indicated that they work more often with excavator operators and skilled workers, however they communicate less with the same groups. Their satisfaction with the quality of communication and with the headsets increased compared to the previous round, especially for the communication with truck drivers (from 2.8 to 3.3). Although their feeling of safety dropped for working together with large vehicles, there was an increase for other two conditions: working near and passing by large vehicles. At the end of this round, respondents suggested that sound quality should be increased, metallic sounds should be reduced, a cable should be used for making the headsets fit better, sound isolation should be increased and noises from outside should be removed.

During round 2, localization warning as a new function was added to the Bluetooth headsets. Compared to previous two rounds, respondents indicated that they work less frequently together with excavator operators, truck driver and skilled workers. However, they communicated more frequently with all these groups. Their satisfaction with the quality of communication with these groups reached to its peak in round 2, while satisfaction with the headsets dropped from 3.5 to 3.2. For all three conditions, respondents felt safer compared to previous rounds. With localization warnings being added, it is natural that round 2 became the safest round for the respondents. This time, respondents also had less suggestions for improvement which were broadening of warning radius to 50 meters and warnings from far away being problematic.

In order to fix the problems reported from round 1, natural interaction behaviour (NIB) function was introduced in round 3, which allows short-range high-quality communication with headsets in high noise environments. During this round, respondents worked less frequently with excavator operators, truck drivers and skilled workers compared to previous rounds, and they also communicated less often with these groups. This might be associated with the quality of communication since respondents rated that they are less satisfied with the quality of communication. Their level of satisfaction with headsets remained almost the same (3.1). Their feeling of safety dropped to the lowest in this round, compared to others (3.0 in average). At the end of round 3, respondents suggested that headsets should function in longer distances, a minimum 25 meters.

All functions from previous rounds were introduced in the final round together. While the frequency of working together with the three groups did not change, they communicated more often with excavator operators and skilled workers in the round 4. Satisfaction with the quality of communication with the three groups dropped to its lowest in this round and satisfaction with the headsets was as low as round 0, where simple Bluetooth headsets with no adjustments were used. On the other hand, respondents felt safer compared to the previous round. The respondents mentioned the following problems at the end of round 4: (i) it should function in distances of minimum 25 meters, (ii) noise cancelling function does not work well, it might be designed for sites where they work very close to each other and (iii) lots of disturbances in machine operators' headsets.

4.3 Summary

Tabel 1 displays the results of the survey rounds. In the case project it was more common to work together or close by excavator and personnel compared to trucks. The gap between how often they work together or close by a group and how often they communicate with the same group does not change drastically in different rounds. In average, respondents rated that they work together or close by personnel more often than other groups. When it comes to communication, excavator operators are more often communicated compared to others, while truck drivers being the least communicated group. Satisfaction with quality of communication with groups differ between rounds. Satisfaction with quality of communication for all three groups follows a linear increase until the round 2, following a linear drop to round 4. Similarly, satisfaction with headsets follow a similar pattern, reaching to its peak in round 1 already and then dropping gradually until round 4. When it comes to feeling of safety, in all three situations, respondents feel most safe in round 2 and least safe in round 3.

Table 1: Frequency of working together with or close by a group and frequency of communication with different groups

	Round 0 (N=15)	Round 1 (N=14)	Round 2 (N=10)	Round 3 (N=7)	Round 4 (N=11)	Average
Favourite method of communication	Verbal communication without headsets	Telephone via Bluetooth	Telephone via Bluetooth	Telephone via Bluetooth	Telephone via Bluetooth	Telephone via Bluetooth
Frequency of…						
Working together or close by an excavator	4.3	4.4	4	3.6	3.5	3.96
Communication with an excavator operator	4.1	4	4.3	3.7	3.9	4
Working together or close by a truck	3.8	3.6	3.5	3	2.9	3.36
Communication with a truck driver	3.4	3.1	3.3	2.9	2.6	3.06
Working together with or close by personnel	4.3	4.4	4.2	3.9	4	4.16
Communication with personnel	4.2	4.1	4.3	3.4	3.9	3.98
Satisfaction with…						
Communication with an excavator operator	3.3	3.4	3.8	3.4	2.8	3.34
Communication with a truck driver	2.8	3.3	3.3	3.1	2.5	3
Communication with personnel	3.4	3.6	3.8	3.4	3.0	3.44
Headsets	2.8	3.5	3.2	3.1	2.9	3.1
Feeling safe while…						
Working together with large vehicles	3.3	3.2	3.5	3.0	3.3	3.26
Working near large vehicles	3.1	3.2	3.5	3.0	3.3	3.22
Passing by large vehicles	3.0	3.3	3.4	3.0	3.0	3.14

5 Conclusions and Further Research

Previous studies reported limitations of different communication methods on construction sites. In this paper, we revealed that basic communication methods such as verbal communication and hand signals can be influenced by many disturbing factors. Weather conditions such as rain and sun can limit vision of operators, creating potential threats for safety. In tunnels, excessive noise limits verbal communication. In darker places, turning on the lights of machines help vehicle operators while reducing vision of skilled workers.

Different functions of Bluetooth headsets were tested in order to investigate whether the Bluetooth headsets are a good solution for reducing communication difficulties on sites. Functions involved in the round 1 and 2, simple Bluetooth headsets with localization warnings, satisfied the construction workers most. Further on, the complaints were mostly directed towards the cover range of Bluetooth headsets where construction workers expected localization warnings, communication quality and noise cancellation function working better even in longer distances.

This paper is based on a single case study from Sweden where buildings are shorter compared to other countries. Therefore, the physical distance between workers is not as much as it is in countries where skyscrapers are built more often. Moreover, this study is based on perceptions of the workers and whether they felt safe and satisfied with the level of communication. Although fatal accidents on construction sites are rather rare in many countries, the strive towards zero fatalities can benefit from new technologies. In future studies, investigating usefulness of Bluetooth headsets in a longitudinal study where different projects are followed from beginning to end, can allow comparisons of measures, based on facts including number of incidents and accidents.

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Urban Sustainability Transformation Through Building Adaptive Pathways

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Abstract
It is becoming apparent that inappropriate infrastructure is one of the main reasons that climate change targets are not being achieved. The structure of existing infrastructure and systems perpetuate unsustainable working and living patterns and it is difficult for people to avoid environmental impacts such as carbon emissions, even if there is a will to do so. Methodologies are therefore needed to understand how existing infrastructure and built environments can be transformed to enable low carbon lifestyles. A potential methodology for achieving this is called Building Adaptive Pathways. The study presents the methodology and illustrates how this can be applied through a case study urban site in Pretoria, South Africa. Findings generated by the application of the methodology, and the methodology itself, are critically reviewed to ascertain the value of the approach. The study concludes that the methodology presents a valuable alternative approach for addressing urban sustainability transformation and makes recommendations for its further development.

Keywords
Sustainability, urban, transformation, Building Adaptive Pathways.

1 Introduction

It is increasingly clear that climate change targets are going to be difficult to achieve. One reason for this is that there has been insufficient change and existing infrastructure and systems perpetuate living and working patterns that are associated with high carbon emissions (Pachauri, et *al*., 2014). Climate change programmes have generally focussed on technological solutions, such as the introduction of solar water heaters or more efficient lighting (Pachauri, et *al*., 2014). These changes however have not had the required result and have only made marginal improvements. The lack of progress in making more rapid progress towards the achievement of climate change targets has prompted interest in approaches that advocate more radical, structural change with greater associated impacts.

The International Panel of Climate Change (IPCC) confirms that approaches based on incremental change have not been successful. They find that these approaches tend to cost more and miss significant opportunities to achieve change compared to transformational approaches (Pachauri, et *al*., 2014). Transformational approaches combine economic, social, technological actions to address climate change and promote sustainable development at the same time. An iterative, structured process, based on learning and innovation, is used to reconcile different goals and develop integrated solutions (Pachauri, et *al*., 2014).

The immediate priority of this approach is to reduce vulnerability to climate change within local communities, and therefore methodologies respond to contexts and site conditions. Synergies and trade-offs between climate responses and broader sustainable development objectives are identified, evaluated, and consolidated to chart practical, high impact development pathways. While this approach appears promising, it has not been applied widely (Pachauri, *et al.,* 2014).

An exception is the Adaptive Pathway approach that was developed as a methodology to tackle climate change adaptation (Werners, *et al.,* 2021; Lin, *et al.,* 2017). This provides a flexible responsive approach that can be used to plan for climate change and has been applied to infrastructure such as sea defences.

This study explores how this methodology can be adapted for built environments. The study presents the Adaptive Pathway methodology and shows how it can be applied. Using an exploratory research approach, the study adapts and applies the methodology to a case study site in Pretoria, South Africa. The results of this application are critically evaluated to ascertain the implications and the value of the approach. The study aims to address the following questions:

- How does the Building Adaptive Pathway methodology work?
- How can it be applied to the built environment?
- What are the results of applying the methodology?

2 The Building Adaptive Pathways

The Building Adaptive Pathway methodology has been developed from the Adaptive Pathway field (Gibberd, 2021). The Adaptive Pathway field is relatively new and was developed in 2010 as a way of dealing with uncertainty and change associated with climate change adaptation (Werners, *et al.,* 2021; Lin, *et al.,* 2017).

The field offers tools that are used in three main ways. Firstly, these are used to understand climate change adaptation and develop plans for this. Secondly, they have been used to promote collaborative learning. Thirdly, tools have been used to manage the complexity and long-term change (Lin, *et al*., 2017).

The Adaptive Pathways approach has been applied to flood risk planning (Jeuken, *et al.,* 2015; Lawrence and Haasnoot, 2017), developing resilient waterfronts (Kingsborough, *et al.,* 2016), sustainable development planning (Sadr, *et al.,* 2020), the development of small-scale PV systems (Michas, *et al.,* 2020) and water supply planning (Cradock-Henry, *et al.,* 2020; Klijn, *et al.,* 2015) but not directly to built environments and urban planning.

Building Adaptive Pathways refer to plans developed to navigate future change in built environments in a proactive structured way (Gibberd, 2021). Future changes are identified as key thresholds or tipping points that change the conditions of a stable system into another state (Butler, *et al.,* 2016). By identifying these points, the methodology draws on different actions to develop a path that steers around these events, enabling disruption to be avoided (Kingsborough, *et al.,* 2016). This path provides a plan that enables future change to be addressed in built environments.

The Building Adaptive Pathway methodology, therefore, envisages and preempts future change by proactively catering for this. For the methodology to work effectively, insight into the nature of future change is required. It also requires an understanding of how this future change can be catered for.

3 Methodology

This study follows an exploratory research approach. This is appropriate when a field is at an early stage and methodologies have not been fully developed or tested (Stebbins, 2001). It is suitable for research that is interested in investigating a new area and developing and testing new ideas (Stebbins, 2001). Exploratory research carried out in this study aims to provide a basis for future research into how uncertainty and change can be addressed in built environments (Glaser and Strauss, 2017).

It investigates how the Building Adaptive Pathway approach can be developed and applied to built environments as a way of planning for future change and uncertainty. The Adaptive Pathway methodology follows an 8-step process. This process has been adapted for buildings in this study and is outlined below.

First, the system that will be addressed by the methodology is described. This includes describing the system's characteristics, the objectives of the system, the constraints in the current situation, and potential constraints in future situations.

Second, alternative future situations, opportunities and vulnerabilities are identified. These are analyzed to understand their potential impacts.

Third, possible actions that can be taken to address future situations are identified. These actions respond to the opportunities and vulnerabilities identified. Action can include physical changes to the environment, or management or policy changes.

Fourth, actions are evaluated to ascertain whether they are effective at addressing vulnerabilities and creating opportunities. Actions that are not effective are discarded.

Fifth, information from the earlier steps are used to create an Adaptation Map. This shows actions, decision points and tipping points. An example of this is shown in Figure 1.

Sixth, the Adaptation Map is evaluated to define preferred pathways. This reviews the pathways, timescales, and constraints such as capacity or finance, to develop a plan that ensures that future change is catered for.

Seventh, a contingency plan with corrective actions in case of unexpected events is developed. This plan can be used to fast-track, or slow down, actions enabling a responsive approach.

Eighth, the earlier stages are used to develop the final Adaptive Pathway Plan which can be shared with key stakeholders and refined, before being adopted.

In this study, the above steps are applied to an urban case study. Findings from this process are then critically evaluated to develop conclusions and recommendations for the study.

4 Urban Case Study

The urban site selected is a low-density residential site near the central business district of a city. The site is in a residential neighbourhood and there is limited social infrastructure or retail where products such as food can be purchased. Most travel to and from sites within the neighbourhood is by private vehicle. The site selected consists of a large house occupied by 2 people. The house is surrounded by a large garden and has not been upgraded so has inefficient water and energy fittings.

The site was chosen as it is typical of many underutilised residential sites found in cities globally. The location, the low density and unsustainable systems of the site are representative of the type of infrastructure and built environments that are found globally and will have to be transformed to support achieve climate change targets and the achievement of the Sustainable Development Goals. Data for the case study was gathered through fieldwork and online mapping tools within Google Maps (Google, 2021). The application of the 8-step Building Adaptive Pathway methodology to the case study is presented next.

2.1 Describe the study area

The first step requires the system to be described. This includes understanding the system's characteristics, the objectives of the system, the constraints in the current situation, and potential constraints in future situations.

The system here can be defined as the site, the immediate neighbourhood surrounding the site and the occupants. In terms of this study, the objective of this system is the achievement of living and working patterns that support the achievement of the climate change targets.

As this study has a focus on transformative actions, the key characteristics of the system that will be investigated are occupancy density, water and energy systems and the availability of services and products and work opportunities. These characteristics have been selected as they are the key factors that affect carbon emissions associated with living and working patterns (Younger *et al.,* 2008; Goldstein, *et al.,* 2020; Wiedenhofer, *et al.,* 2018).

Figure 1 shows the residential neighbourhood that the site is located. The suburb is about 2km from the central business district (CBD) of Pretoria, South Africa.

Figure 1. Case study residential neighbourhood, Pretoria, South Africa

Figure 2 shows the site plan (left) and a section of the site (right). The site plan shows a swimming pool (1), the main house (2) which is about 200m^2, the garden (3), a garage building (4) and the street (5). The house is occupied by 2 people, one is unemployed and the other commutes to work.

An analysis of the site indicates that this does not support low carbon living and working patterns and therefore the achievement of climate change targets. The low density does not support low carbon mobility in the form of walking and cycling and public transport. The existing building has dated fittings such as electrical geysers and high-capacity toilet cisterns, so is highly energy and water inefficient.

Climate change and poor maintenance have resulted in municipal energy and water tariffs that are escalating rapidly, and supplies are also increasingly unreliable (Statssa, 2016). Local access to products and services required for everyday life is limited and products like low-ecological footprint food which support low carbon lifestyles are not readily available. The lack of commercial space and activities within the neighbourhood means that local job opportunities are limited and these can only be accessed through a commute.

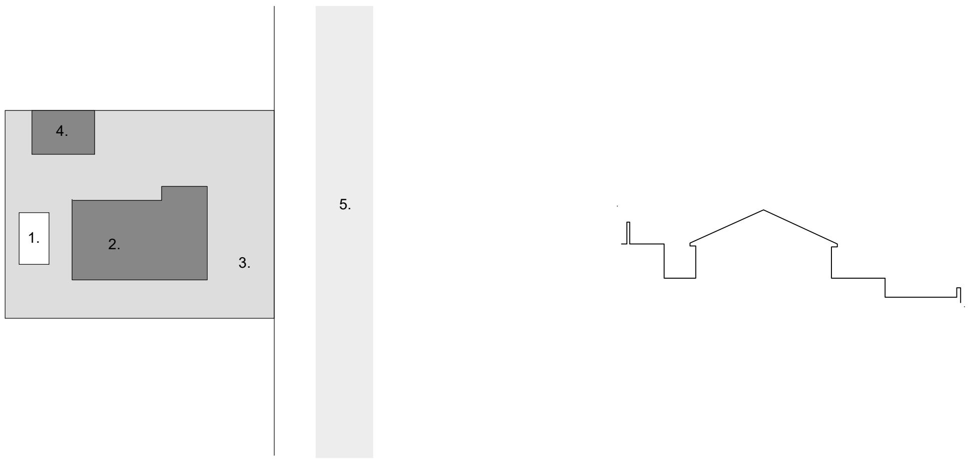

Figure 2. Case study site within a residential neighbourhood, Pretoria, South Africa

Supporting climate change targets will therefore require the transformation and the establishment of sustainable systems. A range of possible future scenarios is possible. The household may have insufficient income to meet ongoing increasing tariff, rates and tax costs related to the property and move out to avoid going into debt. Alternatively, a structured transformation of the site could be embarked on. This would ensure that costs remained affordable by sharing these between more users.

The site offers a range of opportunities. Investments in water and energy efficiency measures could be used to reduce running costs. Additional residents could be accommodated to share costs. Onsite businesses could be included to provide additional income to meet operating costs and provide jobs.

The following vulnerabilities are identified. There may not be the will by current occupants to share the property and accommodate changes. Current occupants may also not have access to the capital required to accommodate additional residents and start onsite businesses.

2.2 Possible actions

Possible actions identified based on an analysis of opportunities and vulnerabilities are as follows. Firstly, measures can be taken to reduce water consumption through the installation of more efficient fittings and the use of greywater recycling and rainwater harvesting systems. This will reduce operating costs, carbon emissions associated with pumping and the reliance on an unreliable municipal supply. Secondly, measures can be taken to reduce energy costs by installing more efficient equipment and installing renewable energy systems such as solar hot water and photovoltaic systems. This will also reduce operating costs, carbon emissions and reliance on an unreliable municipal grid. Thirdly, additional accommodation could be provided on the site. This would reduce operating costs as costs were shared amongst more occupants. Higher densities would also reduce carbon emissions as energy and water systems could be more efficient and public transport and walking supported. Fourthly, small businesses could be developed on the site. These would reduce operating costs as these were shared amongst more users. They could also generate local employment resulting enabling more local income to be generated to cover operating costs. Local businesses would also reduce carbon emissions by making available services and products, such as fresh fruit and vegetables with low carbon footprints were within walking distance of residents.

2.3 Evaluate actions

The actions identified in 'Possible Actions' are evaluated in this stage. This assesses the action in terms of vulnerability, opportunity and date required. The vulnerability assessment reflects the extent to which the proposed action resolves vulnerabilities identified. The opportunity assessment evaluates whether new additional opportunities are created as a result of the action. The date required assessment indicates the date by which the action should be taken to address the vulnerability. This evaluation is shown in Table 1.

Table 1. Pathway scorecard for the project (author).

Actions	**Vulnerability**	**Opportunity**	**Date required**
Water measures	++	+	1-2 years
Energy measures	++	+	1-2 years
Residential expansion	+++	++	3-5 years
Commercial inclusion	++	+++	5-8 years
Key			
Address vulnerabilities fully	+++	Creates new opportunities	+++
Partially addresses vulnerability	++	Partially creates new opportunities	++
Does not address vulnerability	+	Does not create new opportunities	+

2.4 Assembly of pathways

The information from previous steps is used to assemble pathways and create an Adaptation Map with a portfolio of actions that address vulnerabilities and create opportunities for the building. This is shown in Figure 4. Once this map has been created, possible pathways can be identified and evaluated.

2.5 Preferred pathways

Figure 4 shows possible actions and pathways. It indicates that the current situation is unsustainable and that within the next 3 years will reach a tipping point. This tipping point is when the household is not able to afford the operating costs in the form of energy, water, rates and taxes for the site while at the same time water and energy supplies become increasingly unreliable. To avoid this, energy measures can be taken to reduce energy consumption from the municipal grid through more efficient fittings and renewable energy systems. Similarly, water measures can be taken to reduce water consumption from the municipal grid through efficient fittings, greywater systems and rainwater harvesting systems. While these measures help achieve carbon emission reductions and operational cost savings, the capital costs of these systems are substantial. In addition, these measures do not address the issue of density.

Residential expansion could be undertaken to increase density by accommodating more residents on the site. Capital costs of sustainable off-grid systems could be shared between more users making these more affordable. However, this measure does not address access to local products and services and job opportunities.

Commercial inclusion, which is the addition of small business units on the site could help address this issue. This could be used to support more sustainable living and working patterns and reduce carbon emissions as enterprises such as a local greengrocer and small repair business mean that residents can access local work opportunities as well as services and products that promote low carbon living.

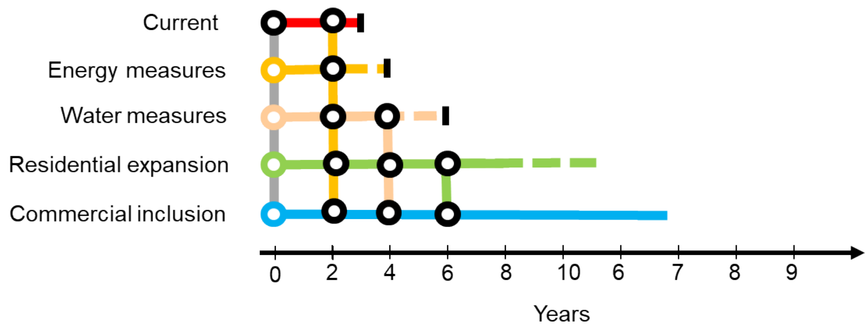

Fig. 3. Building Adaptive Pathways for the project (author).

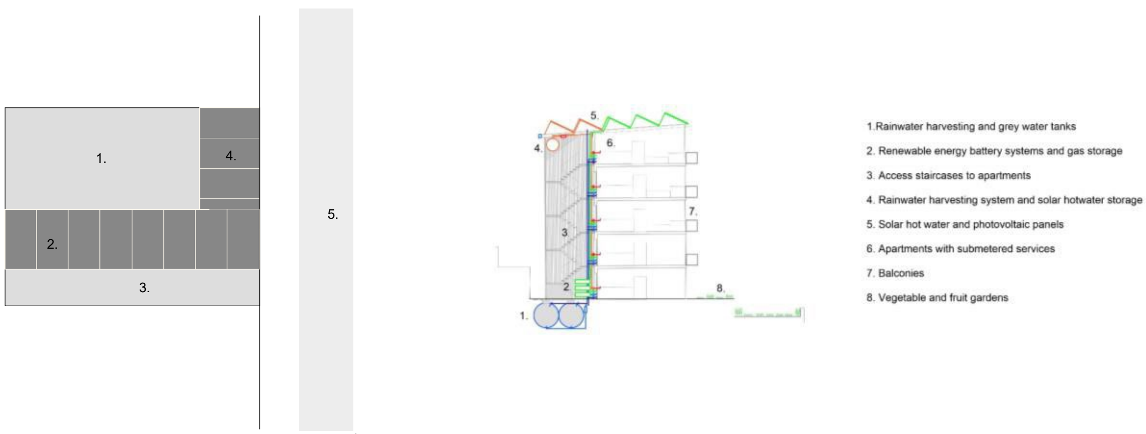

Figure 4. Redevelopment of the case study site within a residential neighbourhood, Pretoria, South Africa (author).

The result of these actions could result in the type of development shown in Figure 4. This shows the developed plan of the site with gardens for recreation and food production (1), residential apartments (2), a service area for renewable energy, rainwater and greywater systems and recycling (3) and small commercial activities (4). This is also shown in the section which indicates the different sustainable systems that would support low carbon living and working patterns.

2.6 Contingency planning

A contingency plan would be developed to enable corrective actions to be undertaken to stay on track in case of more rapid change or unforeseen events. This plan would include triggers and contingency actions that responded to these events. Key actions and associated triggers and responses are outlined in Table 2.

Table 2. Contingency plan for the project (author).

Actions	Trigger	Response
Energy measures	Annual energy increases over 10% Energy outages for more than 2 days	Fastrack transformation
Water measures	Annual water increases over 10% Water outages for more than 2 days	Fastrack transformation
Residential expansion	Continued/increasing lack of affordable accommodation in well-located sites. Continued/increasing lack of reliable and affordable public transport to outlying residential areas.	Fastrack transformation
Commercial inclusion	Continued/increasing high unemployment rates Continued/increasing lack of support for small enterprises and access to local sustainable products and services.	Fastrack transformation

This shows that how trigger events such as rapid increases in energy and water tariffs as well extended energy and water outages would result in the fast-tracking of the transformation of the site. Residential expansion fast-tracking would be triggered by continued or increasing lack of affordable accommodation in well-located sites as well as the continued or increasing lack of public transport to outlying residential areas. Similarly, commercial inclusion would be fast-tracked if there was continued or increasing levels of unemployment and continued or increasing lack of support for small enterprises and access to local sustainable products and services.

2.7 Dynamic adaptive plan

The results from the early steps can then be developed into a Building Adaptive Pathway plan. This provides a plan for the transformation of the site. The plan provides objectives, the actions and phasing, contingency plans, and costs. The rationale for the plan and the implications of not implementing this should also be provided. This enables a comprehensive plan to be understood and implemented by decision-makers.

5 Discussion

The study indicates that the Building Adaptive Pathway can be applied to built environments. The structure of the methodology is simple and easy to use. Steps in the process are considerably different to conventional built environment development plans and provide valuable insight into alternative ways that can be used to transform built environments.

A review of the approach needs to answer the following questions. Does the methodology align with the IPPC's proposed approach outlined at the beginning of the paper? Secondly, does the methodology appear to provide useful ideas and tools for achieving the type of transformation required?

A review of the approach suggests that it aligns well with the IPCC proposed transformational approach. The Building Pathway methodology encourages a transformational approach through the following characteristics. Firstly, it requires the objectives of the system to be defined, and thus, in this case, climate change becomes an explicit goal from the onset. Secondly, the approach requires vulnerabilities and opportunities to be identified. This assessment encourages the investigation of the issue in a broader, more lateral way and is likely to increase the variety of actions, including social, economic and technological options, that are considered. It also promotes an approach that is responsive to the local context and issues. Thirdly, the approach includes a stage during which actions are evaluated to ascertain whether they will achieve stated objectives. This helps avoid incremental or insufficient solutions as actions that do not sufficiently contribute to transformation are discarded.

Proposed actions developed by the approach include the development of sustainable energy and water system systems, residential densification, and the inclusion of commercial activities. The solutions are more radical than conventional climate change programmes that may include options such as improved lighting and solar water heating. The level of change offered by the actions developed through the Building Adaptation Pathway approach is much more significant and transformational than conventional incremental approaches. The approach also appears to encourage the consideration of co-benefits. For instance, proposed energy and water measures not only significantly reduce climate change impacts (environmental) they also reduce operating costs (economic), reduce the negative effects of water and energy outages (social and economic) and create jobs (social and economic). In resource-constrained contexts, such as developing countries, these co-benefits may be important tools for promoting change as they ensure important social and economic objectives such as improved health and education and employment are addressed at the same time as climate change.

Conclusion and Recommendations

To address climate change it is becoming apparent that our built environments need to be transformed. This study adapts and applies the Adaptation Pathway methodology as a means of planning this transformation. Results from this process indicate that a range of actions can be generated and evaluated. It also shows that a responsive, flexible plan can be developed.

Initial results indicate that the methodology provides a distinct departure from conventional built environment development approaches. Actions identified through the application of methodology appear to align well with the type of transformational change promoted by the IPCC. It is recommended that further work is carried out to develop and refine this methodology.

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Studying Buildings Outlines to Assess and Predict Energy Performance in Buildings: A Probabilistic Approach

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Abstract
Building energy performance is commonly calculated during the last phases of design, where most design specifications get fixed and are unlikely to be majorly modified based on design programs. Predictive models could play a significant role in informing architects and designers of the impact of their design decisions on energy consumption in buildings during early design stages. A building outline is a significant predictor of the final energy consumption and is conceptually determined by architects in the early design phases. This paper evaluates the impact of a building's outline on energy consumption using synthetic data to achieve appropriate predictive models in estimating a building's energy consumption. Four office outlines are selected in this study, including square, T-, U-, and L-shapes. Besides the shape parameter, other building features commonly used in literature (i.e., Window to Wall Ratio (WWR), external wall material properties, glazing U-value, windows' shading-depth, and building orientation) are utilized in generating data distribution with a probabilistic approach. The results show that buildings with square shapes, in general, are more energy-efficient compared to buildings with T-, U-, and L-shapes of the same volume. Also, T-, U-, and L-shape samples with the same area show very similar behaviours in terms of energy consumption, regardless of their wall-to-floor ratios. Principal Component Analysis (PCA) is applied to assess the variables' correlations on data distribution; the results show that wall material specifications explain about 40% of data variation. Finally, we applied polynomial regression models with different degrees of complexity to predict the synthesized building models' energy consumptions based on their outlines. The results show that degree 2 polynomial models, fitting the data over 98% R squared (coefficient of determination), could be used to predict new samples with high accuracy.

Keywords
Building Energy Performance, Building Outline, Wall-to-Floor Ratio, Machine Learning

1 Introduction and Background

Buildings account for about 40% of carbon emissions in the US due to their large amount of energy consumption (US Dept. of Energy, 2012). Schematic-phase design decisions could have a huge impact on the buildings' energy use; however, energy performance evaluations are usually postponed to the final phases when design modifications are costly if possible (Hygh *et al.* 2012, Krygiel and

Nies 2008). Although schematic design accounts for a relatively low portion of the total design fee, it is responsible for the main environmental impact and operating cost of the final buildings' performance (Krygiel and Nies 2008). Selecting efficient building parameters in the early stages of design could improve buildings' energy performances (Hatem and Karram 2020). Multiple buildings' parameters are studied in literature as effective variables that could have significant impacts on the final energy consumption of buildings, including building's geometry, envelope property, window property, Window to Wall Ratio (WWR), and building's orientation, which are chosen by architects mostly in the early phases. Conceptual buildings' shapes and geometries are one of the important decisions architects take in the early phases, upon which, they further improve the design process (Okudan and Tauhid 2008). Energy simulation tools provide a fairly accurate prediction of a building's energy performance when all specifications are considered in the simulation process; however, many design decisions may not be deterministically made in the early phases, yielding to a poor prediction result (Amasyali and El-Gohary 2018). Achieving efficient design parameters requires investigating multiple design alternatives. However, applying simulation tools for all design alternatives is costly and time-consuming (Shaghaghian and Yan 2020). Also, most energy simulation tools require sufficient knowledge and expertise to implement. Hence, the significance of practical tools in providing performance-based information to the designers in the early stages of design is crucial (Hygh *et al.* 2012).

Data-driven approaches and predictive models have been studied in literature as statistical methods to approximately predict buildings' energy performances without a step-by-step calculations (Seyrfar *et al.* 2021, Amasyali and El-Gohary 2018). Such methodologies are specifically useful for providing performance-based information at a fast pace in the early stages of design to help architects select building parameters based on their target variables (Abarghooie *et al.* 2021, Nourkojouri *et al.* 2021). Although having the information of the existing buildings as the input data for the data-driven approach is undeniably beneficial, the accessibility and difficulty in the information retrieval have propelled many studies into utilizing synthetic models and simulations in providing the required training data for predictive models (Amasyali and El-Gozhary 2018, Reddy 2006). Multiple studies in literature have explored building shape as a key parameter in building energy simulation and predictive models (Asl *et al.* 2016, Hatem and Karram 2020, Nazari and Yan 2021). Rahmani asl (2016) has developed a form-based tool to seamlessly predict a building's energy simulation in the early phases of design. In his study, most form-related parameters, such as building length, width, height, and WWR are considered, while other performance-based parameters such as building orientation wall and window material properties have not been explored (Asl *et al.* 2016). In another study, researchers have investigated buildings shapes along with other performance-based variables to evaluate building energy consumption; however, no predictive model is developed in their study (Hatem and Karram 2020). Also, both studies have used deterministic values in generating their data samples while uncertainty is one of the major issues needed to be considered in existing versus simulated data that could help in yielding more practical results (Shahsavari *et al.* 2019).

The focus of this study is developing regression models to predict building energy performance in the early phases of design considering different buildings' outlines. Four building outlines, i.e., square-, T-, U-, and L-shapes, are selected for this study inspired from a similar study done by Hatem et al., 2020. The present study illustrates the impact of building shape on developing predictive energy models with high accuracy. To generate synthetic data for training the predictive models, we considered eight performance-based building features commonly introduced in literature, namely, building orientation, Window to Wall Ratio (WWR), windows' shading-depth, glazing U-value, wall thickness, wall conductivity, wall density, and wall Specific Heat Capacity (SHC). The last four features are the properties of buildings' wall material used in similar studies (Kouhirostamkolaei *et al.* 2021). Literature shows that, in practice, an existing building's features often deviate from the pre-assumed/simulated values (Reddy 2006). This deviation leads to unexpected errors in estimating the final building's energy consumption (Rezaee *et al.* 2018). However, to avoid such uncertainties, one can perform simulations with artificially added Gaussian noise to the expected values of a building's features and, therefore, estimate the energy consumption along with the possible practical deviations (Macdonald 2002). This paper has conducted an uncertainty approach used in similar studies (Shahsavari and Shaghaghian 2021) to consider the features' deviations reported by literature among existing building and simulation models. In this paper, thermal load and total energy consumption are used interchangeably, referring to a building total energy demand (heating and cooling) to keep occupants in thermal comfort zone. We analysed the data using visualization methods in displaying the data distribution. Principal Component Analysis (PCA) is applied as a feature selection technique to observe the impact of the independent variables used in this study on data variation. Finally, regression models are developed to predict data samples based on their shape outlines and the eight building features implemented in the simulations.

2 Research Methodology

This study applies Rhino/Grasshopper, a parametric modelling platform, to generate hypothetical office buildings, with four shape outlines and eight numerical building features commonly used as variables for building energy consumption in literature. A probabilistic approach is utilized in generating the data using the Gaussian distribution. The energy consumptions of the synthesized samples are computed through parametric energy simulation plugins, Ladybug/Honeybee. Data visualization methods are utilized to analyse data distribution. Variables' covariances have been analysed through PCA as a feature selection method, and finally, polynomial regression models are applied to get the best-fitted models to predict the target variable, i.e., total thermal load, given the input features.

2.1 Data Generation

A hypothetical open office plan is parametrically generated in Rhino/Grasshopper considering. The energy consumption of all building models are simulated parametrically through Honeybee with the EnergyPlus engine considering 100 m^2 area with 5 meter height (minimum length of building side is 2.5 m). The four building outlines selected for this study are displayed in Figure 1.

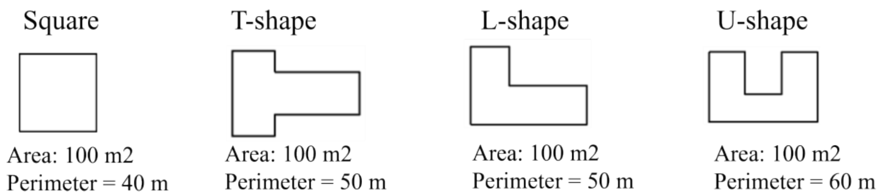

Figure 1. Building plan outlines based on (Hatem and Karram 2020)

This study has used a statistical method to consider uncertainty in the simulation process to address the deviations between the pre-assumed/simulation outcomes and buildings' performances in practice reported in literature (Bae *et al.*, 2020, De Wit 2001). Artificial noise was employed to impose uncertainty to the simulated values of the features to calculate the buildings' energy consumptions with probable deviations that occur in practice. A common choice of artificial noise is a random variable distributed as a univariate zero-mean Gaussian distribution. In other words, for the j^{th} feature a noise can be sampled from a univariate zero-mean Gaussian distribution with a standard deviation of σ_j. In this study, for each feature, a set of possible values are considered. Tables 1 and 2 represent all variables (building features) utilized in this study. Table 1-column 2 shows the possible values considered for each feature and Table 1-column 3 represents the number of possible values associated with the feature. The total combination of all features leads to 1440 (5×4×3×12×2) conditions per building shape. Hence, in this study, we generated 5760 samples (1440 per building outline). The amount of means and standard deviations of the variables corresponding to the wall material specifications, i.e., wall thickness, conductivity, density, and specific heat capacity, have been derived from studies in literature (Macdonald 2002, Hopfe 2009) (Table 2). For the rest of the features, due to the lack of literature, we added a Gaussian noise with σ = 0.01 per each possible value (Table 1-column 4). We determined this amount to generate a normal distribution around each possible feature value while respecting the intervals between them so that they don't overlap. However, we considered a larger variance for the building orientation parameter to address the high uncertainty of buildings' orientations during the early design stages (Macdonald 2002). Studies show that a perturbation of 5° on the building orientation could result in a significant uncertainty on the solar fraction that is often overlooked by designers (Almeida Rocha *et al.* 2016). Hence, to address the high level of uncertainty and cover a wide range of buildings' orientations due to the variation of actual urban grid orientation, we used σ = 3 for the building orientation parameter. This amount will cover the perturbation of 5° reported in literature in a probabilistic approach. Other energy simulation parameters have been considered constant across all samples. We adopted those values from ASHRAE standards (ASHRAE Standards, 2013) used in similar studies (John Haymaker *et al.* 2018).

Table 1. Buildings' variables, sets of possible values, and standard deviations used in data sampling

Variables	Set of Possible Values	Number of Possible Values	Standard Deviation (σ)
WWR	{0.1 , 0.2, 0.3, 0.4, 0.5}	5	0.01
Windows' shading depth (m)	{0, 0.15, 0.30, 0.45}	4	0.01
Glazing U-value (W/(m2·K))	{0.7, 2.72, 4.54}	3	0.01
Building Orientation (degree)	{0º, 30º, 60º, …, 330º}	12	3
External Wall Material *	* Table 2	2	* Table 2

Table 2. External wall material choices along with means (μ) and standard deviations (σ) adopted from literature

* External Wall Material	Thickness (m)	Thermal Conductivity (W/m·K)	Density (kg/m³)	Specific Heat Capacity (J/kg·K)
Concrete	(μ =0.21, σ =0.021)	(μ =1.13 , σ =0.1)	(μ =2000 , σ =30)	(μ =1000 , σ =106)
Brick	(μ =0.16 , σ =0.016)	(μ =0.84 , σ =0.27)	(μ =1700 , σ =297.5)	(μ =800 , σ =86)

To generate the data samples the following method is applied:

Let ($\mathbf{x}_n$, y_n) be the n^{th} sample, where $\mathbf{x}_n$ is an 8-dimensional feature vector and y_n is the corresponding response variable (i.e. building's energy consumption). Each data point is generated as described in the pseudo code below (Listing 1), and is used as an input vector to the energy simulator to generate the corresponding y value.

Listing 1 Pseudo code to generate the n^{th} data sample

1 For j in [1, 2, …, 8]:
  Randomly, select a value from the set of possible values corresponding to feature j
  Add a Gaussian noise with σ_j around the selected value
2 Generate the n^{th} sample $\mathbf{x}_n = [x_1 , x_2 , \dots ,x_8]$, where x_j is the j^{th} feature
3 Generate y_n, by sending $\mathbf{x}_n$ to the energy simulator

4 Return ($\mathbf{x}_n$, y_n)

2.2 Data Analysis

To analyse the data, multiple methods have been utilized. Initially, we adopted exploratory data analysis to assess the impact of building's shape on the total energy consumption rate. Figure 2 depicts the probability distributions of thermal loads corresponding to the four selected outlines.

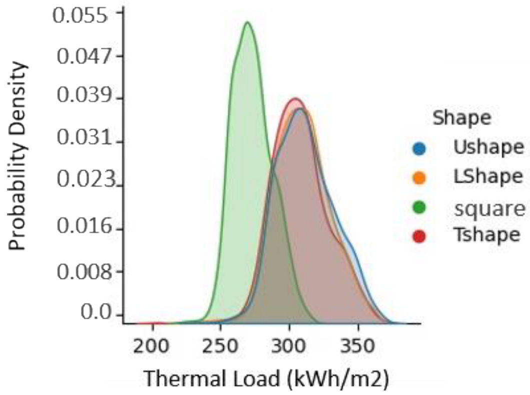

Figure 2. Probability distribution plot of thermal loads across the 4 selected buildings' shapes

Figure 2 demonstrates that the thermal loads of building models with T-, U-, and L-shapes have similar probability distributions although they have different wall-to-floor ratios (see Figure 1). Also, the average thermal load of buildings with square outlines (272.92 kWh/m^2) is lower than the average thermal loads of buildings with T-,U-, and L-shapes (309.64 kWh/m^2). Furthermore, the standard deviation of the thermal loads corresponding to the square shape (14.53) is lower than the other three shapes (20.4 on average). In other words, considering noisy features that commonly occur in practice, thermal loads of buildings with square shapes are mostly distributed around the mean; hence, the simulated values tend to be closer to the expected values with higher probability compared to the other outlines. Expected values refer to the thermal loads calculated with deterministic features that are commonly used in energy simulation methods. Table 3 represents the quantitative comparative analysis of the building models' thermal loads with respect to their shape outlines.

Table 3. Minimum, maximum, mean and standard deviation pertained to thermal loads of building models with different shape outlines

Building Shape	Minimum Thermal Load (kWh/m2)	Maximum Thermal Load (kWh/m2)	Mean Thermal Load (kWh/m2)	Standard Deviation (σ)
Square	222.27	317.16	272.92	14.53
T-shape	203.54	368.61	307.63	20.53
U-shape	234.18	369.54	311.56	20.9
L-shape	232.34	362.64	309.72	19.74

Table 3 leads to the following conclusions:

- The average minimum thermal loads of building models with T-, U-, and L-shapes is 0.5% higher than the minimum thermal load of building models with square shapes.

- The average maximum thermal loads of building models with T-, U-, and L-shape is 13.6% higher than the maximum load of building models with square shapes.
- The average thermal load of building models with T-, U-, and L-shape is 11.9% higher than the average thermal load of building models with a square shapes.
- The average deviation of the thermal loads of building models with T-, U-, and L-shape is 28.98% higher than the deviation of the thermal load of building models with square shapes from their corresponding means.

It is important to mention that the results reflect the significance of building outlines besides the wall-to-floor ratio impact on buildings energy consumptions.

2.2.1 Variables' correlations and significance

Principal Component Analysis (PCA) is a non-parametric statistical technique for data dimensionality reduction (Wold et al. 1987, Ghane et al. 2015). PCA transforms data points along different axes which contain information of the original variables. The transformation process (projection) produces linear combinations of the original variables with the eigenvector's coefficients through axes known as PCs (Principal Components) (Ghane 2015). Hence, the total number of PCs aligns with the number of variables although the PCs do not coincide exactly with any of the original variables. Through PCA we can assess the relationship among variables and their impact on data distribution. Depending on the variables' correlations, often the first few PCs explain the major variation of data. The results from PCA could be utilized to summarize and visualize the informational content of a large data with multiple variables through tables and figures. The loading matrix derived from the PCA method shows the weight, i.e., coefficient, of each variable across the corresponding PC. Hence, the absolute value of the weights explain how much each variable contributes to a specific PC. The negative or positive sign only represents the direction of the corresponding eigenvector. Thus, large values, regardless of their sign, indicate a strong contribution of a variable to a particular PC. Since the primary PCs represent the major variation of data, the weights of the corresponding variables indicate their significance to data distribution. Figure 3 depicts the scree plots of the PCs; left: percentage of variance explained by each PC, and right: the cumulative percentage of the variance retained by the PCs.

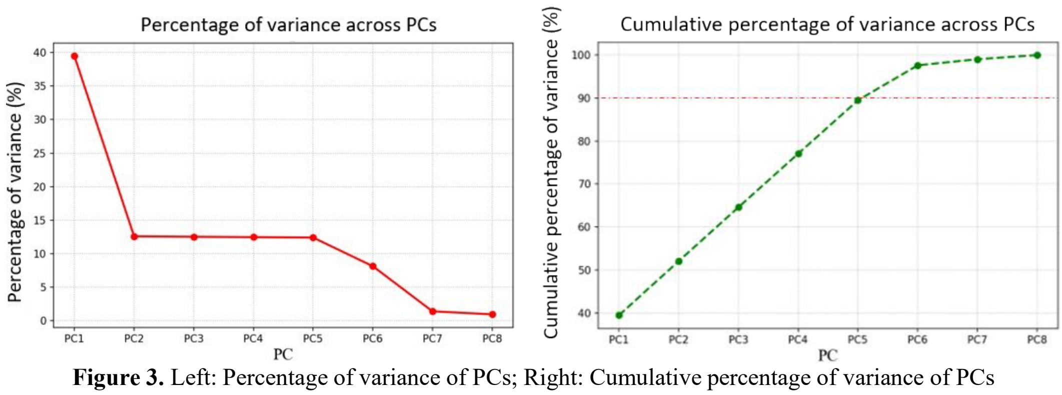

Figure 3. Left: Percentage of variance of PCs; Right: Cumulative percentage of variance of PCs

Figure 3-left demonstrates that PC1 explains ~40% of data variation, while the next four PCs (PC2 to PC5) account for ~12.5% of data variation each. Based on the cumulative (sum) of the variance percentages, the primary five PCs are required to explain 90% of the variance in the data (Figure 3-right).

Table 4 shows the loading matrix, including the variables and their corresponding coefficients across each PC. The highlighted cells indicate the variables' weights which have relatively strong contributions to the corresponding PCs among PC1-PC5.

Table 4. Loading matrix; coefficients of variables across PCs

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Orientation	0.0066356	0.2367618	0.759922	0.23574	-0.55666	-0.01739	-0.02938	0.001466
WWR	-0.001685	-0.138909	0.540427	-0.74829	0.357905	0.01706	-0.02218	-0.00498
Shading depth	0.0194056	-0.682932	0.320954	0.534051	0.373885	-0.07206	0.009134	-0.01162
Glazing U-value	0.0140875	-0.679363	-0.17096	-0.30661	-0.64403	0.004916	-0.01373	-0.01547
Wall thickness	-0.832547	-0.029016	-0.00622	0.003005	0.000642	-0.04546	-0.20402	0.512328
Wall conductivity	-0.698691	-0.039503	0.044839	0.045921	0.000365	0.629432	0.323426	-0.07456
Wall density	-0.719927	0.02969	0.002896	-0.05547	-0.02847	-0.51854	0.443622	-0.10698
Wall SHC	-0.797497	0.0117432	-0.02544	0.017823	0.017048	-0.03774	-0.47105	-0.37348

Table 4 displays that wall material specifications with relatively high coefficients significantly contribute to PC1. The rest of the variables, i.e., orientation, WWR, shading, and glazing U-value, also contribute to PC2-PC5 with relatively high coefficients. As previously mentioned, PC1 and PC2-PC5 explain 40% and 50% of the data variation, respectively. Therefore, all features selected in this study have relatively high or nontrivial correlation across at least one of the primary PCs; hence, no feature is eliminated for training the prediction models in the next section.

Note that PCA is an unsupervised method meaning that it does not take into account the response variable. The PCs are orthogonal axes representing the linear functions of the variables with coefficients corresponding to each variable; however, since PCA does not consider the response variable, i.e., thermal load, the results cannot be inferred as a sensitivity analysis of the features. Saying that, summary statistics (e.g., min, max, mean, etc.) may not be conducted upon PCA loading matrices. In this study PCA was only used as a feature selection technique to determine whether any of the selected dimensions (variables) could be neglected.

2.3 Prediction Models

Finally, the study has explored Polynomial regression models with different degrees of freedom (degree 1 to 4) to predict the response variable, i.e., thermal load, knowing the input features. The degrees in the polynomial models affect the complexity of the models. For example, the simplest polynomial model is a linear regression model with a degree of 1. Note that regression models require numerical values for all features. Therefore, we had to either ignore the form feature or consider separate models for each form. Assigning dummy variables with numerical values to the form feature may not be an appropriate solution since each form is not numerically better or worse than the other one. Hence, two conditions are studied, including: 1) using all data ignoring building-shape feature and 2) splitting data based on building-shape feature and using separate models for each case. Based on our primary analysis explained in the "Data Analysis" section, the data is split into two sets of samples in the second condition, including building models with square shapes and building models with T-, U-, and L-shapes. R squared (R^2), i.e., coefficient of determination of the prediction model, is used as a metric to determine the goodness of the fitted model. R^2 normally ranges between 0 and 1 (0% - 100%) where 0 is the worse and 1 means the exact fit. Another issue to address in this study is overfitting phenomena. Overfitting is a common incident that happens when the model fits too much into the training data and fails in predicting the test set in the real world

(Tom Dietterich 1995). Different methods are introduced in literature to avoid overfitting (Bartlett *et al.* 2020, Braga-Neto 2020). In this study, although statistically we have a huge amount of data, all data is synthetically generated from one source; hence, train and test samples are very similar to each other. To generalize the model and avoid overfitting, only a small portion of the data (30%) is used for training, and the rest is kept for testing (70%). Table 5 shows the results of R^2 on test data using polynomial regression models with different degrees across the two conditions as follows:

1) Considering all samples and ignoring building-shape feature (Table 5, condition 1).
2) Samples of building models with square outline versus T-, U- and L-outlines; hence, considering separate models for each of the two categories (Table 5, condition 2).

The training time corresponding to each predictive model is also calculated (column-3) to reveal the impact of model complexity on computational time.

Table 5. R-squared and training time pertained to prediction models considering the two conditions

Prediction Model			R^2 (%)	Training Time (milliseconds)
Condition 1	All samples ignoring form feature	Linear Regression (degree = 1)	71	0.0047
		Polynomial Regression (degree = 2)	79.5	0.0083
		Polynomial Regression (degree = 3)	78.7	0.0785
		Polynomial Regression (degree = 4)	74.3	233.27
Condition 2	Samples with square shapes	Linear Regression (degree = 1)	86.9	0.0017
		Polynomial Regression (degree = 2)	98.3	0.0064
		Polynomial Regression (degree = 3)	97.7	0.069
		Polynomial Regression (degree = 4)	88	358.2476
	Samples with L,T, and U shapes	Linear Regression (degree = 1)	87.2	0.003
		Polynomial Regression (degree = 2)	98.4	0.008
		Polynomial Regression (degree = 3)	98.6	0.0803
		Polynomial Regression (degree = 4)	98.3	244.68

The results show that considering separate prediction models for square shape buildings versus buildings with T-, U-, and L-shapes can better fit the data. Considering one general model in predicting the response variable of all buildings with different shapes has not exceed R^2 of 79.5%, whereas the separate prediction models respecting building shape feature could reach to R^2 of 98%. This result matches with the analysis explained in the "Data Analysis" section, validating the difference between thermal loads' distribution of buildings with square outline versus T-, U-, and L-outlines. Therefore, the results confirm the impact of buildings' shapes on total energy consumptions. Also, in most cases, the polynomial models with degree of 2 are the best fitted models. More complex models with higher degrees have not necessarily resulted in better fits for this dataset while they take exponentially more computational time to get trained. The computational time is calculated based on the current study training sample size and could increase if the training input increases. The prediction model for T-, U-, and L-shapes shows better result with degree = 3 with only 0.2 % improvement compared to the model with degree = 2; the computational time has increased by 90% which is a significant leap.

The plots in Figures 4 to 6 display the relation between predicted values to simulated values of test data using the selected prediction models over the samples in the two conditions previously explained. The degrees of the models have been increased form 1 to 4 (left to right) in the figures where the most left plots correspond to the models with degree = 1 (Linear Regression), and the most right plots correspond to the polynomial models with degree = 4.

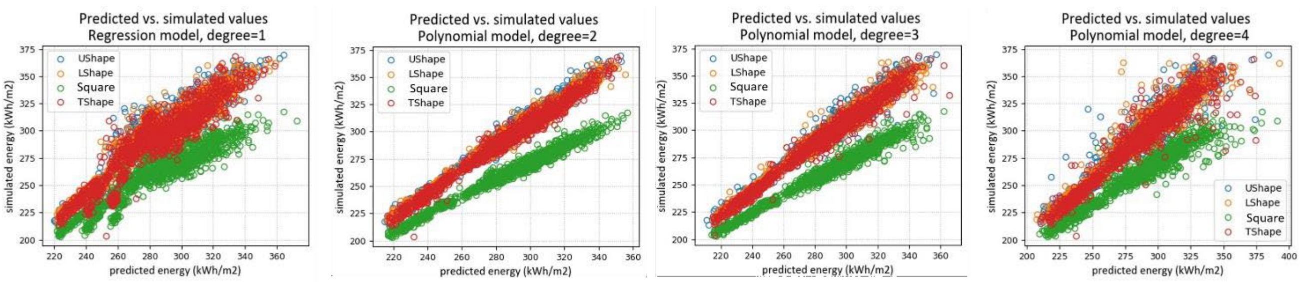

Figure 4. Plots of polynomial models (degree 1 to 4, from left to right) considering all data, ignoring building outline feature.

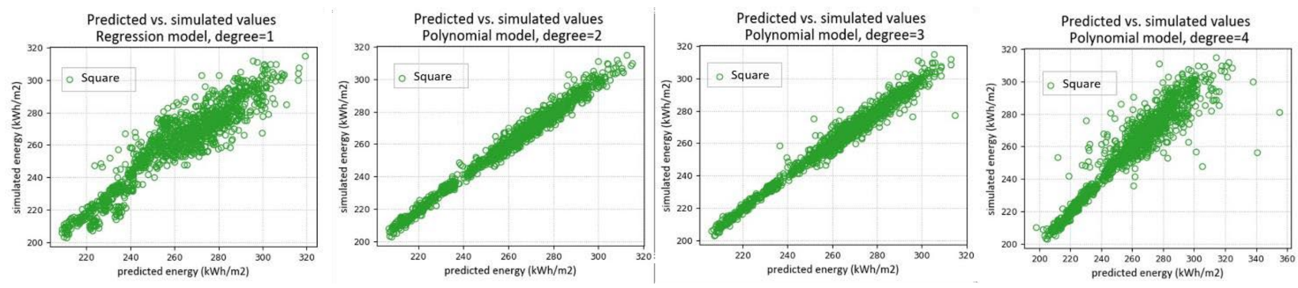

Figure 5. Plots of polynomial prediction models (degree 1 to 4, from left to right) for samples of square-outline building models.

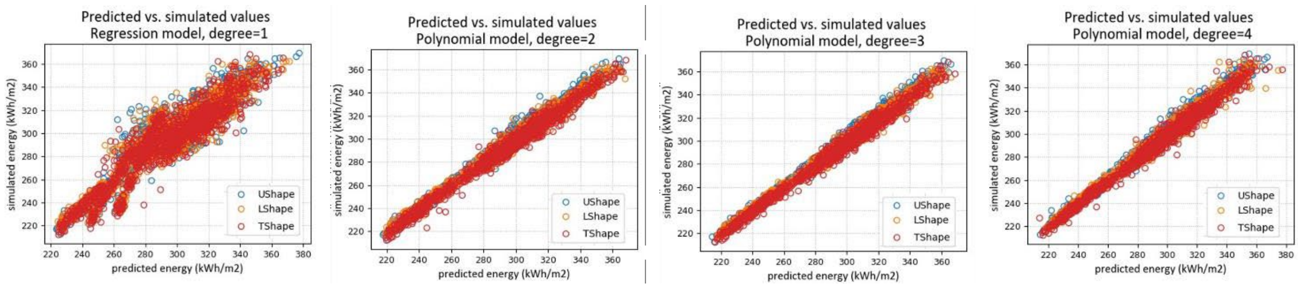

Figure 6. plots of polynomial prediction models (degree 1 to 4, from left to right) for samples of T-,U-, and L-shape building models.

3 Conclusions and Further Research

This study explored the impact of buildings' outlines on developing accurate predictive models to predict buildings energy consumptions. Eight performance-based parameters are considered in generating synthetic data for each building outline. Due to the deviations reported in literature between simulated and actual values, we implemented Gaussian noise to apply probability to the features values. In total, 5760 feature vectors were synthesized (1440 per building outline). Subsequently, the feature vectors were used to simulate the thermal load.

Our results show that the probability distributions of the simulated thermal loads were similar for buildings with T-, U-, and L-shape outlines although they had different wall-to-floor ratios. The buildings with square outlines, on average, consumes 11.9% less thermal loads than buildings with T-, U-, and L-shape outlines. This result matches with the study done by Hatem et al., 2020, confirming that square outlines show more efficiency in energy consumption compared to other outlines with similar area (Hatem and Karram 2020). The results also reflect that considering uncertainty for feature values, thermal loads of buildings with square shapes are mostly distributed around the mean with a higher probability (mean = 272.92 , std = 14.53) compared to the other shapes (average mean = 309.63 , average std = 20.4). Therefore, we may expect the thermal loads of the square-outline building models with lower uncertainty around the mean compared to other shapes.

Additionally, we investigated the contribution of features in the data variation by means of PCA. The result form PCA method indicates that PC1 retains 40% of data variation, whereas the set of next four PCs explain 50% of the variation. Hence, the primary 5 PCs are required to explain ~90% of data variation. The major contributors to PC1 are wall material specifications, i.e., wall thickness, conductivity, density and specific heat capacity. For the next four PCs, other performance-based parameters, i.e., building orientation, WWR, glazing U-value, and window shading depth, have significant impact. Therefore, all of the aforementioned features are important in energy consumption of the synthetic data and may not be neglected for training predictive models.

Based on the analysis of the impact of a building outline on the response variable, i.e., thermal load, predictive regression models with different complexities are developed. The regression models with degree of 2 perfectly fit the data in most cases while being computationally and timely more efficient than models with higher degrees. In addition, models with higher degrees are prone to overfit the training data, and therefore may not predict the unseen samples with high accuracy. We assessed the goodness of fits using R squared metric. The results show that fitting a mono-predictive model for all samples, regardless of outlines yielded R^2 = 79.5 %. The goodness of fits increased by fitting two separate models; one model on the samples of square shape (R^2 = 98.3%) and one model on samples with the T-, U-, and L-shapes (R^2 = 98.6%).

In the future study, the authors intend to consider other building outlines and their variations to cover vast variety of building shapes. Also, we plan to develop more complex non-linear algorithms, such as SVR (Support Vector Regression) and DNN (Deep Neural Network), to examine if a single, complex model could accurately fit all data variations, yet not overfit the training data, covering several building outlines.

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Track 4

Digital Engineering and BIM

Investigating the Drivers & Challenges of Implementing Immersive Sensory Technology within Construction Site Safety

Towards a Hybrid Approach to BIM Implementation – A Critical Discourse

BIM in Facilities Management. Has COVID-19 Widened the Gap between Academia and Practice? A Case Study from Dubai

Barriers to Effective Digital Leadership Enactment in the Construction Industry

Integration of Data and Information

Communication Challenges in Building Energy Efficiency Retrofits: Croatia Case

Investigating the Drivers & Challenges of Implementing Immersive Sensory Technology within Construction Site Safety

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Abstract

The use of immersive sensory technology for safety management is generally shown positively in academic literature. Many researchers have demonstrated applications of this technology for improving safety training in a risk-free environment. Despite the reported benefits and a global pandemic forcing the digital agenda, the uptake of this technology for this purpose remains slow. This study aims to investigate current drivers and challenges of implementing this technology for safety from an industry-based perspective. To achieve this, qualitative data was collected through 4 online focus groups involving 21 industry professionals working within the field. The findings identified that even amongst these experts, the technology was rarely implemented on projects specifically for safety. Despite this lack of adoption, participants agreed that if implemented correctly this technology has the potential to enhance site safety processes such as inductions, tool box talks and general safety training. The commitment to safety and legislative requirements were identified as key drivers, whilst deep rooted challenges surrounding client demand, costs and leadership dominated the discussion. The onsite practicalities, personal comfort and lack of digital skills were also identified as concerns if this technology was to be adopted more mainstream in safety training. Further recommendations are made to develop understanding of these specific challenges, including investigating the industry need and availability of specific skills in immersive safety applications. In addition, it is recommended that further empirical evidence including the impact of this technology when implemented for safety on projects is provided in literature.

Keywords
construction, immersive technology, safety.

1 Introduction

The construction industry remains among one of the most dangerous of all sectors. This is due in part to its high-hazard nature (Li et al., 2018), its traditional reliance on temporary works, heavy site plant and manual tasks which can be difficult to predict (Getuli et al., 2019; Li et al., 2015). These complex and dynamic environments are susceptible to accidents that can result in life changing injuries or fatalities (Le et al., 2014). According to the HSE (2021) 39 fatalities were reported in Great Britain in 2020 / 21, more than any other major industry. The moral and legal drivers should place safety as top priority (Hughes & Ferrett, 2016); supported by investment and ongoing development of innovative tools and techniques to reduce risks. Whilst much can be commended regarding the industries safety improvements in recent decades, there is still a desperate need to develop and further reduce accidents on site.

Despite the construction sectors strides in digital transformation, the often repeated criticisms related to deep-rooted issues including the need to modernise are still a concern (Farmer, 2021). Even with mandated processes, forward-thinking organisations and a global pandemic forcing the digital agenda, the industry is still falling behind. Fast-paced global technological developments have resulted in high specification immersive applications (such as virtual reality) being an available and affordable option for mainstream use. Within the construction sector the potential benefits of immersive sensory technology for safety purposes has been subjected to research for many years (Swallow & Zulu, 2020a). According to Smith (2020) the construction industry is at "*a tipping point*" regarding the adoption of immersive technology, stating "*now is the time to start paying attention*". The use of immersive technology has generally been presented in a positive ligh t within literature, identifying opportunities in safety training and planning with increased engagement (Sacks et al., 2013; Swallow & Zulu, 2020b). The ability to carry out activities such as scenario based training in a risk-free virtual environment has been researched by many (Olugboyega & Windapo, 2019). Despite the reported benefits, the use of immersive technology in the industry is not widely adopted (Ghobadi & Sepasgozar, 2020). Whilst research has begun to investigate the general challenges to its adoption (Delgado et al., 2020; Ghobadi & Sepasgozar, 2020) few have focused on the industries perspective for its specific integration in safety management.

Therefore, this study aims to take an industry-based view of the current drivers and challenges to identify recommendations for implementing this technology for safety purposes. In order to meet these aims, qualitative data was collected through a series of online focus groups. These groups were made up of industry experts within construction who had varied exposure to its use. Through thematic analysis, key themes were detected throughout the qualitative data sets. This study identified safety legislative requirements and remote working were assisting in the adoption of this technology. However, the low demand from clients and lack of leadership were seen as root causes for its limited use. The need for skills and investment along with on-site practicalities were identified as specific challenges for its wider adoption in the field of safety.

2 Literature Review

For safety purposes, immersive technology offers an interactive, virtual risk-free environment which can be the ideal solution for training and to communicate safety risks. According to the NBS (2020) in the 10th annual BIM report, 38% of those surveyed are currently using virtual / augmented reality technology (although this is not specific to safety purposes). For many years, the use and effectiveness of immersive technology for safety has been questioned in the construction sector. Whilst the RIBA (2020) recommended that such technologies should be taken seriously, these are yet to be commonplace on construction projects (Delgado et al., 2020).

The low uptake of technology in the construction industry has led to much debate and the specif ic factors have been investigated by many researchers. Specifically related to the adoption of AR and VR, Delgado et al. (2020) carried out research into the factors that limit and drive its adoption in the construction industry. Using a combination of industry focus groups and online questionnaires, the study reported that the technology enabled improvements in project delivery however is limited due to unsuitability and high costs. A similar aim was set by Ghobadi & Sepasgozar (2020) who also investigated issues that have prevented the widespread adoption of immersive technology within the sector. In this study, interviews with academics found that high costs, software and hardware requirements in addition to low accessibility were key barriers. Despite the number of studies that have investigated drivers and challenges of this technology, there is limited research from an industry perspective or specifically to safety applications.

3 Research Methodology

This research aims to explore an industry-based perspective of the current drivers and challenges to the implementation of immersive sensory technology for safety purposes. To satisfy the research aim, online focus groups were conducted to collect qualitative data from active industry professionals. Individuals within the fields of digital management, contract management, safety, commercial and design, were asked to take part to ensure views from across the industry were included. The use of focus groups for qualitative research is a reliable and popular method in many fields (Guest et al., 2017) including construction disciplines and in safety research. Online focus groups are similar in most aspects to traditional face to face aside from the virtual nature of the interaction (Nyumba et al., 2018). The choice of an online environment as a platform for data collection was primarily due to government lockdown restrictions. However, the use of modern online virtual platforms assisted in both the accessibility for participants (who otherwise my not have been able to attend) and the ability to accurately capture the group discussions.

The number and size of the focus groups is important to consider, taking into account research practicality and saturation. Guest et al. (2017) carried out research into focus group sizes, suggesting that an average number of groups needed to identify 90% of themes was 4.3. In relation to the size of these groups, McQuarrie & Krueger (2015) suggested that the ideal size is between five and eight per group as larger groups would limit the individuals to share their thoughts and observations. In this study, the recruitment process used selective sampling to ensure participants who engaged with the study had a minimum of 5 years in the construction related sector and held management positions. As shown in table 1, a total of 21 participants contributed to the study and were allocated into groups, each group included a range of roles, ages and experiences in order for participants to exchange interdisciplinary views. The focus groups began by participants providing a brief overview of their role and exposure to immersive technology when used specifically for safety purposes. They were then asked a series of pre-determined questions (Hennink et al., 2019) to explore their views on drivers and challenges within the sector. This allowed for discussions to be open, yet provided the structure to maintain the groups focus on the topic. These focus groups were recorded via an online conferencing platform with verbal discussions transcribed for accurate accounts and analysed using NVIVO 12 software. Deductive thematic analysis techniques were subsequently used, synthesizing higher level codes and clusters of codes under focus themes (Romigh et al., 2017; Vasilevski & Birt, 2020; Vieira et al., 2014).

Table 1 Industry Participant Summary

	Participant	Role	Years in industry	Number of employees	Adopting Immersive tech for safety?
Focus group 1	FG1 Participant 1	Architect	31-40	1-20	never
	FG1 Participant 2	Project manager	5-10	21-50	rarely
	FG1 Participant 3	Client project manager	31-40	Over 1,000	never
	FG1 Participant 4	Civil engineer	21-30	Over 1,000	never
Focus group 2	FG2 Participant 1	4D modeller / consultant	21-30	1-20	rarely
	FG2 Participant 2	4D modeller	5-10	21-50	never

	FG2 Participant 3	Innovation manager	5-10	Over 2,000	rarely
	FG2 Participant 4	BIM manager	5-10	Over 4,000	often
	FG2 Participant 5	Director project planner	11-20	1-20	rarely
	FG2 Participant 6	Planning / data consultant	5-10	21-50	rarely
Focus group 3	FG3 Participant 1	Contract's manager	31-40	51-100	never
	FG3 Participant 2	Commercial manager	11-20	51-100	never
	FG3 Participant 3	Contract's manager	21-30	21-50	never
	FG3 Participant 4	Quantity surveyor	11-20	51-100	never
	FG3 Participant 5	Company director	11-20	1-20	never
Focus group 4	FG4 Participant 1	Digital manager	11-20	Over 7,000	rarely
	FG4 Participant 2	Structural engineer	5-10	100-500	never
	FG4 Participant 3	Visualisation specialist	5-10	Over 2,000	rarely
	FG4 Participant 4	Head of digital	21-30	Over 40,000	rarely
	FG4 Participant 5	4D planning manager	5-10	Over 5,000	rarely
	FG4 Participant 6	Digital engineer	11-20	100-500	rarely

4 Findings and Discussion

As part of the focus group discussion, participants were asked to introduce themselves with a brief background of their role, size of organisation and whether they used immersive technology specifically for safety purposes. These initial questions identified that out of the 21 participants, only one had often used it, 10 indicated that it was rare and 10 had never used this technology specifically for safety. Subsequent questions and discussions focused on the drivers and challenges to the adoption of immersive technology for safety purposes. On analysing the transcripts two main themes were identified as drivers, and within challenges there were five themes. Organisational and industry were key across both, with challenges also including individual, technological and project based themes. Figure 1 illustrates these themes and their relationships to the transcripts, each of the five themes are presented in further detail with discussions taken from the focus groups.

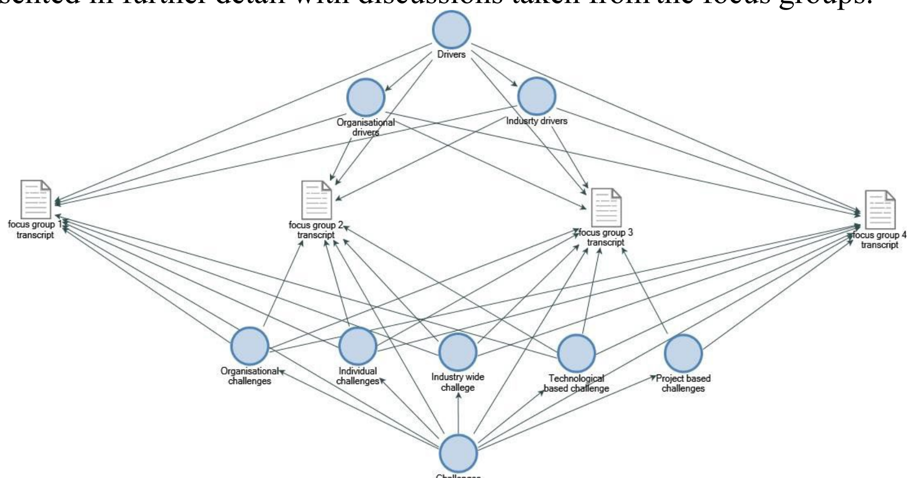

Figure 1 Drivers and Challenges focus themes

4.1 Organisational

This theme linked to drivers and challenges mainly surrounding organisational adoption. It was clear from the focus groups that immersive technology has much to offer in terms of integration within organisational safety management systems, such as "*you can use it for identification, and you can* *use it through management*" (FG2 Participant 1). This said, many in the groups stated that the technology was not used for practical safety applications. For example, FG2 Participant 2 suggested "*…it was a bit of a gimmick to engage with the client, it was more of a sales pitch than actually a tool that was used for anything practical*" and FG4 participant 2 stated *"I have only worked for companies who buy a headset and have a desktop computer to run it but it was more of a gimmick and did not find a useful way of using it"*. From these discussions in various groups it was clear that many companies have invested in the equipment however have not used this practically for onsite safety purposes, more as marketing tools. The benefits of immersive technology for safety was explored within the focus groups, for example FG1 Participant 4 stated:

> "*it will definitely have a role for safety - it is inevitable. For tool box talks this could support the verbal discussions, this illustrating it and them putting on the headset walking about in the digital world and spotting the potential hazards"*

The potential advantages of risk-free training was agreed by several participants, stating that organisations needed to be forward thinking in regards to their safety practices. Although participants unanimously agreed on practical uses of this technology for safety management, when it came to implementation the challenges for organisations dominated the discussion, with one participant suggesting "*It all comes down to cost, it's the cost time and resources*". In addition to costs, a lack of organisational leadership, investment and awareness were common themes stated by many, including:

> "*The people who pay for things in our industry don't really know what they are buying in innovation – they just see it as tech… it needs leadership. It needs someone to say "this is not a gimmick, we are actually going to plan our projects using these tools"* (FG2 Participant 1)

The financial implications associated with purchasing such equipment was directly referenced in every focus group. Participants also discussed this in relation to the size of the organisations, suggesting challenges are from both limited funds and due to a lack of skills in smaller companies. On this topic, FG1 Participant 4 stated "*they might not see it as necessary because of the costs associated. The smaller builder is concerned with making money on the project and see this as unnecessary work and costs*". Concerns around organisational resources and project costs were also highlighted, specifically discussing the use of immersive technology in common safety activities such as site inductions: "*it's the people to be able to manage it, to develop it, monitor it, to amend it. All of these people… who pays for them*?*...it would cost a fortune*" (FG3 Participant 3). Although, FG2 Participant 5 questioned the term 'cost' leading to a discussion regarding organisational commitment and investment to new ways of working, stating "*defining the purpose of it and seeing it as an investment rather than a cost. I mean how much do construction companies put into research and development? Nothing really*".

4.2 Individual

During the online focus groups many challenges emerged that often stemmed from an individual hesitancy to use the technology. FG4 Participant 6 noted "*There is still a reluctance to use it… and I can see as to why - that is as people are not comfortable going into that environment*". Links to personal comfort were discussed in focus group 4, mainly surrounding symptoms of motion sickness and vertigo whilst using VR. Reflecting on this, FG4 Participant 2 shared their experience "*Yeah vertigo, I remember I was put into a tower crane and it feels really high! It's scary! You know its fake but you don't want to edge too far forward*". Although many have recommended that these technologies be incorporated (RIBA, 2020) this study has found that some doubtful perceptions of this technology remain in the industry, for example FG3 Participant 2 suggested "*I think the big* *challenge in the uptake is changing that perception. Clearly this does have practical benefits, it is getting beyond that scepticism and selling it to people to show them what they can get out of it*". The importance of individual perceptions was expressed by many, one participant furthered this by sharing their experience of purposeful implementation and the importance to maintain engagement, stating

> "*It depends on how it is implemented, because if it's a VR headset sat in a corner and you expect people to go and use it to check something – probably not. But if you are doing an induction or having a workshop or working through what your method of work is going to be and you are facilitating that, either taking people through an individual VR scenario or in a group where they don't necessarily have to do the driving then I think you would get more people engaging than leaving it in the corner as a novelty*" (FG2 Participant 6).

A resistance to change traditional safety processes (particularly in relation to site safety inductions) was further explored in all focus groups, from a site perspective several agreed that the common attitude is: "*we have always done it this way… we don't need the gizmos*" (FG2 Participant 6). Some also linked this to previous poor experiences using VR. For example, FG4 Participant 3 stated

> "*Its past bad experience isn't it. We are human and we always remember the bad stuff. I have had clients say to me that they hate VR 'I had a bad experience and felt really sick' but if you say that this one wont they often say 'oh yes it will I have made my mind up'"*.

This reluctance was also specifically linked to the age of individuals. Comments included: "*you are going to get negativity, often from the older generation. They are just not going to buy into technology"* (FG3 Participant 3) and "*If we were to try and inject immersive technology into site safety processes, we will always get that backlash from site teams 'this is how we have always done it'*" (FG4 Participant 3). Increased technology usage following the government lockdowns was highlighted in many groups, FG1 Participant 1 argued that age is not a factor, stating "*necessity is the mother of invention, since I have been working from home, I have had to embrace technology. I think it's more the need rather than the age of people*". Considering the approach of mandating such technology on projects, FG2 Participant 6 suggested

> "*The operatives will probably interact with whatever environment they come into, so it needs to be those people to say - 'so this is how we manage health and safety here, we are going to walk you through this, we are going to expect you to do these things' then those who come onto that site have no choice but to engage with it*".

Although individual benefits were acknowledged, an interesting discussion emerged linking to long term behavioural effects of using this technology for safety training. FG1 Participant 4 stated "*relying on the technology could lead to complacency…youngsters are in danger of relying too much on the technology, without practical experience may leave themselves open to some of the risks that may exist*". Several participants agreed with this, highlighting the importance of experience and the need for practical based training in addition to virtual ones.

4.3 Industry-Wide

Industry wide codes captured a range of drivers including legislation and mandated processes as well as deep rooted challenges linked to culture, a lack of client demand and concerns around digital skills. The current use of technology within safety management was questioned with many participants referring to the industry as still in need of modernisation. To assist with skills, the need to draw in younger generations who have grown up with technology was highlighted. Many participants believed that outdated site processes may discourage some from wanting to start a career in the industry: "*They will probably think they have stepped back in time to the 80 s, a bit of a time warp really. I think a lot of areas of the industry are behind compared to most industries nowadays*" (FG3 Participant 2). This slow adoption of new technologies within construction has often been linked to cultural issues and a resistance to change (Henderson & Ruikar, 2010). The wider concerns around the need to upskill the current workforce as well as the need to recruit new staf f was clear from participants responses: "*Not enough skills*" (FG2 Participant 5) and "*EVERY expertise its struggling with*" (FG4 Participant 1). The question of who should be skilled in this technology was also raised: "*on site you would want your health and safety teams to be the ones that are upskilled because they are ones delivering inductions etc, they're the ones who are driving health and safety* " (FG2 Participant 6). Due to a reported lack of skills within the industry, participants choosing to use immersive technology on projects had to outsource expertise causing higher level management to question these additional resources: "*we had to hire outside of construction, we had to hire a games designer…they would be saying "why do we need game designers? We are a construction company who pour concrete*" (FG2 Participant 1).

A lack of demand was highlighted as a core challenge by many participants who voiced concerns around the client paying for such technologies. For example, FG3 Participant 2 stated:

> "*a big part is the culture of the industry which is very much delivering projects. Clients are cost driven, if you have clients wanting the job done the cheapest way possible, they will not want to be paying a premium for technology which they see as non-essential*"

This said, the need for clients to take an active role in their duties under CDM 2015 were reinforced with comments such as: "*the Clients have responsibility for health and safety…its probably a reason for having immersive technology – it can prove that you have done way above and beyond what you can do to ensure safety*" (FG4 Participant 3). Participants also discussed that many contractors are now taking the lead in health and safety innovation without the demand from clients. FG3 Participant 1 suggested: "*Its new technology and they would lead on it more than the client or any mandatory requirement - because contractors want to reduce accidents*".

4.4 Technological

This theme focused on the readiness and use of the technology for safety purposes. Participants discussed the technologies used in their organisations, focusing on the applications and challenges. The use of virtual reality headsets was commonly identified as a tool used in training and logistics planning. Practicality challenges of this technology were discussed among the groups, with FG4 Participant 1 highlighting:

> "*The next challenge is doing this on mass, if you wanted to induct 30 workers … are you going to have 30 headsets? Would you have enough space to put everyone in a CAVE? Particularly with COVID. So don't get me wrong I think it's really good but it's the practicalities around it*".

Limitations around isolating individuals in headsets were also discussed in many of the focus groups, with the benefits of alternative forms of immersive technology identified: "*I think BIM CAVEs are more effective for training people to bring them into one space rather than isolating someone with a headset on*" (FG4 Participant 4). The cost of these technologies was also identified as a challenge in addition to the accessibility, particularly if used for site safety training. Further ways to integrate immersive technology onto site were shared and compared to other methods such as mobile phone apps. Many were also concerned of the investment into fast-moving technology, for example FG4

Participant 6 stated "*We are not ignoring virtual reality, but we are not sure how long that will last in our business for – it might be there currently but maybe not in a year or two years' time*".

4.5 Project-Based

These codes formed a theme focused on project-based challenges, specifically in reference to the practicalities of using immersive technology for safety inductions and project-based training. In the discussions cost was again highlighted as a key challenge. This referred mainly to smaller projects, with concerns raised around the financial investment and budgets. For example, one participant stated "*I don't know if small scale projects would have the capacity or funding to do it in the first place*" (FG4 Participant 3). Participants spoke of the need for value from investment, for example FG3 Participant 1 suggested "*on smaller sites this type of investment would be huge, and I guess it would on a big site too but the rewards on a bigger site could be better as well*". Concerns over project resources, time and expertise to implement this for safety was widely debated in focus group 4. FG4 Participant 1 stated:

> "*You need a 3D model, you need a decent computer, you need the immersive environment, you need expertise and if they all exist on your project then it does not matter if its small or not, this does not exist on most of the big projects let alone the smaller ones*".

Several participants within this focus group agreed that the lack of these key components would result in this technology not becoming commonplace for safety, or any other purpose.

5 Conclusions and Further Research

The aim of this study was to investigate industry-based perspectives of the current drivers and challenges of implementing immersive sensory technology for the purposes of safety management. The study used focus groups involving industry practitioners who were invited to discuss their views and experiences. Generally, the use of this technology was welcomed as a means to improve safety, however it was found that it was rarely implemented on projects and even rarer specifically for safety. Practitioners acknowledged a drive for this technology and discussed various benefits of it becoming more widely used in safety applications. This mainly focused on providing tools to assist the project team in identifying potential hazards and communicating these effectively. The use of this technology during safety workshops and site inductions was shown to add value to existing methods as well as its use in hazard recognition training. However, there was a mixed view of the practicality and accessibility of VR, concerns regarding personal comfort and its acceptance from the site teams perspective. There was also a concern that using virtual training platforms as a substitute for real-life experiences could lead to complacency, particularly with inexperienced practitioners.

The need for effective leadership, investment and resources to successfully adopt immersive sensory technology within organisations was a common theme. Whilst the participants did explore the challenges of implementation when specifically used for safety purposes, the wider industry issues preventing its more general adoption dominated the discussions. It was apparent that an absence of client demand, the associated costs and lack of specialist digital skills within the industry to produce and manage these immersive environments are root causes. This appeared even more evident in smaller organisations, although it was argued that smaller projects could have the freedom to try new processes if they had the time, expertise and tools. Even with the recent government lockdowns brought about by the COVID pandemic accelerating digital capabilities within the industry, the sustainable adoption of this technology must be driven by clients and organisational management. Without a demand from clients to force the agenda, construction companies are left to choose to adopt this technology. Although many suggested that it's the contractors driving safety innovations, the issues surrounding time, cost and skills would be a challenge only overcome by company investment and upskilling / outsourcing expertise. Whilst the industry is still committed to safety, the matter of cost appears to remain top priority which requires a deeper cultural change. The adoption of technology with the potential to improve safety comes at a cost and is still feared by many, this also linking to a reluctance to change traditional safety processes. Considering the challenges identified in this paper, it is suggested that further research into the digital skills required to implement such technology for safety management on site is investigated. It is also recommended that further research into the practical application of immersive sensory technology on projects specifically for safety be carried out. Documenting further empirical evidence of its application and its impact on project safety outcomes can assist organisations and clients alike to make informed decisions as to its implementation.

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Towards a Hybrid Approach to BIM implementation – A Critical Discourse

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Abstract
BIM adoption in many countries involves different approaches including the use of government mandates. The UK's 2016 BIM mandate for public projects to be delivered at BIM Level 2 maturity, is an example. However, BIM mandates do not apply to private sector projects which leave questions about the inclusivity of its adoption and the susceptibility of SMEs to being digitally disenfranchised. Developing countries yet to adopt BIM are at the risk of out-rightly imitating the mandate-driven policies of countries like the UK, without considering alternative options that might better suit their socio-economic realities. This research investigates the use of alternative strategies (nudge theory) for promoting BIM adoption for inclusivity of smaller organisations, the private sector or developing countries. By drawing on two interrelated yet independent theories of loss aversion theory and nudge theory, this study examines the current mandate-driven policies and provides a critical discourse around ways that these two theories can be combined to form a new kind of construct on the way BIM implementation is (or can be) understood. The result from the critical analysis suggests that a hybrid of mandate and nudge can be effective in promoting BIM and none of these approaches is self-sustaining given their challenges. This finding opens a new vista for applying behavioural policies based on nudge theory and its potentials for promoting BIM implementation in the construction sector.

Keywords
BIM implementation, BIM mandate, BIM policies, Loss Aversion theory, Nudge theory.

1 Introduction

The promotion of Building Information Modelling (BIM) in the Architectural, Engineering and Construction (AEC) industries of many countries have been driven by different kinds of strategies, among which government BIM mandates are popular (Smith 2014). This is despite conflicting opinions about the effectiveness of mandating BIM. Some studies (McAuley *et al.* 2012, Porwal and Hewage 2013, Smith 2014) looked into how realistic a BIM mandate is with respect to two contrasting groups: small and medium scale enterprises (SMEs) and large organisations - with arguments that mandates favour the latter group (Dainty *et al.* 2015). Whilst leaving the SMEs which account for majority of the firms in the AEC industries on the disadvantaged side of the BIM divide. Both SMEs and large organisations vary in size, capability, resources, cash-flow, expertise, etc. (Sexton *et al.* 2006). Hence, BIM implementation may be relatively easier for some while posing a challenge for others and often alluding to liability of smallness (Aldrich & Auster 1986). Governments have intervened on the issue of BIM adoption primarily for its political expedience and for socio-economic reasons (Dainty *et al.* 2015), particularly on the back of decades of documented inefficiencies, waste and slow pace of (or resistance to) change in the construction industry (Latham 1994, Egan 1998). Resistance to change is common in organisations that thrive within cultural practices and habits (Bresnen & Marshall, 2000; Ford, Ford, & McNamara, 2002; Khosrowshahi & Arayici, 2012; Thomas & Davies, 2002). Therefore, in the absence of an external push such as a government-imposed BIM ‘mandate’, some AEC organisations will resist change (Arayici *et al.* 2011, Kassem *et al.* 2012, Vass and Gustavsson 2017) and continue to use outdated processes and technologies. In countries like the UK, public sector projects account for 40% of the construction industry’s workload and the central government is considered the industry’s biggest customer (Cabinet Office 2011), as such BIM could be a procurement policy issue. However, the private sector can neither be mandated nor ignored in the ongoing BIM revolution or evolution.

In recent years, governments have used more subtle approaches for implementing beneficial policies through strategies such as Nudge theory (Thaler and Sunstein 2008). The 2017 Nobel Prize in economics awarded to Professor Thaler for his contribution to this theory and its applications in contemporary policies underscores its widespread acceptability and success. The non-forced compliance approach of nudge could usher wider acceptability of BIM as well as answers to reasoned criticisms by researchers, e.g. Dainty et al. (2015) who argued that government involvement (e.g. by imposing mandates) and the 'hyping' of BIM is beclouding its true value and potential, if not somewhat misleading about its expected benefits. However, the nudge theory and concept have not found its way into the lexicon of BIM research. It is in view of these intertwined issues that this study was undertaken with the following objectives: (i) taking a detached, critical and in-depth look into the realities of BIM adoption from the perspectives of developed and developing countries; (ii) questioning the effectiveness or otherwise of using a government-driven mandate - a reference position for this study; and (iii) exploring alternative or complementary adoption strategies that could be better suited to the nuances inherent in AEC organisations or countries.

2 Review of BIM implementation strategies

This research builds on two interrelated yet independent theories: loss aversion theory and nudge theory that together, can combine to form a new kind of construct on the way BIM adoption is (or can be) understood. These theories can also serve as a basis for evaluating the effects of the types of BIM implementation strategies adopted by change agents.

2.1 Digitizing the AEC industry for BIM: A mandate-driven approach

As the construction industry rapidly enters the BIM era, there have been uptake and support by different governments to help promote its adoption. The various kinds of initiatives on BIM adoption by the public sector have been summarised into six main categories by Cheng and Lu (2015) which include: initiators and drivers; regulators; educators; funding agencies; demonstrators; and researchers. Each category has examples of aspects that relate to it (Fig. 1) which help in clarifying how the public sector has engaged in developing different strategies for implementing BIM. BIM mandate by governments is popular in developed countries like UK, Hong Kong, Finland and Denmark (Wong *et al.* 2011, Tahrani *et al.* 2015), where legislations have been enacted on the use of BIM for public sector projects. The rationale has been that BIM will lead to better project outcomes in terms of project cost, quality and time. Other studies show benefits of BIM in areas such as supply chain management (Le *et al.* 2018), claim management (Shahhosseini and Hajarolasvadi 2018), prefabrication (Mostafa *et al.* 2020) and model authoring processes (Singh *et al.* 2017). In some developing countries, there have also been calls for mandates (Saka and Chan 2019). However, there are opportunities, risks and issues of priorities associated with mandates in both types of countries.

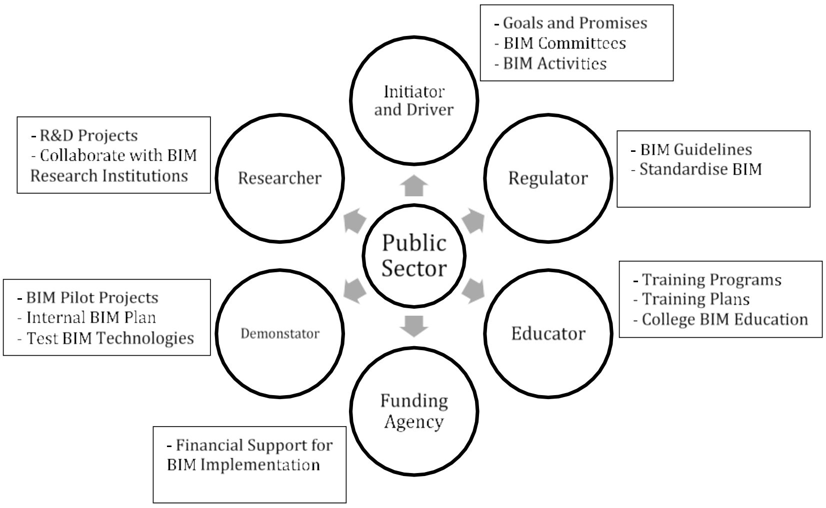

Figure 1: Roles of the public sector in BIM adoption (Source: Cheng and Lu, 2015)

2.1.1 Mandating BIM in developed countries: Opportunities and risks

Government mandate on BIM aims to promote (or speed up) its adoption (Eadie *et al.* 2013, Smith 2014) in developed countries, but different opinions have emerged. BIM adoption in European countries varies from 23% and 25% in Poland and Czech Republic respectively to 74% and 78% in United Kingdom and Denmark respectively (Ullah *et al.* 2019). Some researchers on this subject (Smith 2014; Porwal and Hewage 2013; McAuley *et al.* 2012) believe mandating BIM is the best way to facilitate and increase its adoption and to motivate the industry to embrace newer processes and technologies. Others (e.g. Dainty *et al.* 2015, 2017) have questioned the wider impact of mandate on the industry, including the politicisation (and hyping) of BIM, which feeds into the 'technocratic optimism' that pervades in the higher tiers of the industry (Fox 2014). There is also the erroneous presumption that once technology was in place, all AEC firms would be BIM compliant (Dainty *et al.* 2017) which ignores the skill and usage access of BIM. A government BIM mandate could increase its 'awareness' (McAuley *et al.* 2012) and help stimulate stakeholders towards responding to client and industry needs. Smith's (2014) study of criteria necessary for successful BIM implementation in developed countries found 'government and industry leadership as a critical success factor. However, a downside of mandating BIM (Ayinla and Adamu 2018; Dainty *et al.* 2015) is that in an already fragmented industry, there is a risk of a digital divide emerging between small and large organisations i.e. between those who can comply with the new policy and those who cannot. Specifically, the SMEs are at the risk of being digitally 'disenfranchised' by a BIM mandate due to their incapacity to rapidly mobilize requisite resources to operate at the required BIM maturity level, and thus struggling to win public projects (Ganah and John 2013, Lam *et al.* 2015). In the UK, this would mean SMEs delivering projects at BIM Level 2, which has robust technical requirements found in the standards and guidelines such as BS1192, PAS1192 and ISO 19650 (British Standards Institution 2015; ISO 2017).

SMEs in developed countries dominate their construction industries making up over 70% of the AEC industry's workforce (Dainty et al., 2015; Lam, et al, 2015). They exhibit diverse specialties and capabilities ranging from design, manufacturing and as well as hands-on tradespersons (Rezgui *et al.* 2009). Therefore, imposing a BIM mandate on them could be problematic (e.g. suppliers or sub-contractors) and inadvertently, some risks to the smooth functioning of the industry could be inadvertently introduced. For policymaking, the impact of BIM mandate on SMEs needs thorough consideration from a digital divide perspective. There is little evidence in literature that such impact studies have been carried out since available studies on the drivers of BIM (e.g. Lin *et al.* 2006, Gu and London 2010, Khosrowshahi and Arayici 2012b, Smith 2014) have not studied the consequences of 'digital marginalisation' of SMEs. Nevertheless, while the role of government and national standards for compliance and mass adoption of BIM in several countries cannot be underestimated (Edirisinghe and London 2015), mandating of BIM has been limited to public sector projects and other countries could learn from this.

2.1.2 Mandating BIM in developing countries: A question of priorities

The construction industry in developing countries is also dominated by SMEs (Eyiah and Cook 2003, Kheni *et al.* 2008) meaning they face similar (possibly greater) challenges when it comes to BIM (i.e. lack of client demand, lack of BIM expertise, cost of implementation, etc.) (Saka and Chan 2020). Studies on BIM adoption in these countries are increasing (Khanzadi *et al.* 2018) with the indication that adopting BIM would be more complicated than in developed countries. The level of BIM adoption in Asia was found to be low (Ismail *et al.* 2017) and in Malaysia, Zakaria *et al.* (2013) found that BIM adoption was difficult due to firms not knowing where, when and how to start and the absence of national standards/guidelines. Ahuja *et al.* (2018) found BIM adoption at an early stage in India, while Dim, et al. (2015) revealed that in Nigeria some clients, designers and contractors were not familiar with BIM or what it was all about. Abubakar, et al. (2013) recommended that governments and industry stakeholders should jointly address the identified barriers to BIM adoption. Given the challenges of mandating BIM in developed countries, it is surprising that some researchers focusing on developing countries (Dim *et al.* 2015, Hosseini *et al.* 2015, Musa *et al.* 2015, Ugochukwu *et al.* 2015) have recommended BIM mandates to the government in such countries. Some have argued that lack of government involvement 'worsens the current situation' (Zakaria *et al.* 2013). Besides, even with minimal government involvement, AEC firms in Malaysia seemed prepared to adopt BIM for competitive advantage and due to market demands (Rogers, et al. 2015). Mandating BIM in the near future is, therefore, unlikely to solve the many challenges faced by the AEC industry in countries like Malaysia, India or Nigeria where resistance to change and lack of awareness has been identified as key barriers (Zakaria *et al.* 2013, Dim *et al.* 2015, Ahuja *et al.* 2018).

Moreover, for developing countries, the technology infrastructure (hardware, software and network systems) needs to be available, accessible and affordable because connectivity is a prerequisite for hosting information models (Succar and Kassem 2015). Furthermore, there is widespread utilisation of unlicensed or pirated software in such countries (Bui *et al.* 2016). Instead of forced compliance, gradual adoption in such countries could bring benefits in terms of the learning process, which may be lost when it is mandated for government projects (Ismail *et al.* 2017). Lastly, using coercion for BIM adoption would adversely affect the SMEs which are mostly indigenous firms and would lead to job loss.

2.2 Adopting BIM to win jobs – Loss Aversion

The success of mandating BIM in developed countries like the UK could be linked by the theory of Loss Aversion (Tversky and Kahneman 1991, Gächter *et al.* 2010) which states that people are more sensitive to a decrease in their wealth than an increase in the same. This results in the consequences of losses being weighed twice as much as corresponding gains (Thaler *et al.* 1997). It is plausible to argue that given the well-documented barriers to BIM adoption, it is sometimes implemented by some AEC organisations (e.g. SMEs) because they are loss averse. This means some organisations would adopt BIM even when its benefits to their business, society or the environment are not clear to them but simply because they want patronage on government projects. It is conceivable to expect that such companies will only implement the basic requirement for BIM as required by a mandate without any effort to exploit the well-documented benefits that it offers. This leads to questions about whether a government mandate is actually just an 'enforcer' and not necessarily a 'motivator' for BIM adoption as suggested by some studies (McAuley et al., 2012; Porwal & Hewage, 2013; Smith, 2014). Besides, there are doubts about the effectiveness of the threat of sanctions by defaulters of mandated policies (e.g. regulations and taxes) and whether such sanctions enable policymakers to achieve desired outcomes (Wells 2010) including long-term behavioural change (Hansen and Jespersen, 2013), which for BIM is thought to be more important than technological change (Mc Auley *et al.* 2013). Mandating BIM might hence lead to compliance due to business considerations and not necessarily stimulate long-term change in attitude or behaviour towards the intrinsic value of BIM. Evidence from the UK also suggests professional opinion is split about mandating BIM and its long-term future. Just before the 2016 mandate kicked in, the NBS (2015) survey of professionals showed a slight majority (54%) believed the government was on the 'right track' by placing a mandate on using BIM. Three years after the 2016 mandate, the BIM survey (NBS 2019) revealed that: only 48% of respondents thought the mandate was successful overall; only 32% agreed the mandate was able to sustain the momentum since 2016; and just 22% thought the industry was delivering on the mandate.

In summary, whereas BIM mandates can help increase BIM awareness and promote its adoption and implementation across the AEC industry in various developed countries, there are disadvantages associated with mandates as suggested in literature, including (a) being applicable to only public sector projects meaning the private sector is not directly benefiting since such clients cannot be compelled to use BIM; (b) mandates disenfranchise SMEs due to the existence of the digital divide; (c) mandate may not work for all countries especially those who are developing and are unable to cope with the governance and standards aspects of BIM implementation; and (d) BIM mandates particularly when enforced on SMEs might be attaining compliance due to loss aversion, i.e. adoption is based on fear of losing work while the value of BIM itself is lost; (e) mandating BIM in developing countries should not be a priority until the basic awareness, training and IT infrastructure have been put in place. In light of these points, a rethink is required on the effectiveness of a mandate-driven approach for achieving a holistic adoption of BIM in the entire industry inclusive of SMEs and private sectors. This argument necessitates the exploration of either an alternative strategy or perhaps complementary approaches to be used concurrently with mandates for macro-scale BIM adoption across the AEC industry.

2.3 Digitizing the AEC industry for BIM: The 'nudge' alternative

Governments can bring about social change via a 'motivational' approach or through imperceptible techniques to arrive at desirable policy outcomes. An example of a non-forced compliance concept is 'nudge theory' defined by Thaler and Sunstein (2008) as *"any aspect of choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives"*. Crucially, the intervention must be easy and cheap to opt-out from and should be designed to produce beneficial outcomes that individuals or organisations cannot produce on their own (Thaler and Sunstein, 2008). Many countries have embraced the nudge concept in different aspects of policymaking, with examples seen in Sweden, Netherland, France, Denmark, UK and US (John *et al.* 2009, Oliver 2013). A good nudge leads people towards making positive choices e.g. automatically enrolling people on a pension scheme unless they willingly opt-out (John *et al.* 2009). In this regard, although the importance of pension to the individual and the society is well established, many workers are negligent in setting up their pensions. Therefore, a default automatic pension enrolment for everyone (with opting out made possible) improves the number of enrolled pensioners thereby 'nudging' people to save for retirement. This clearly has benefits for the entire society as it reduces future financial burden on taxpayers due to lack of enrolment by negligent workers (Wells 2010). In the context of this study on BIM adoption, therefore, nudging organisations towards relevant and beneficial design and construction processes by making digital technology and training easily available (e.g. subsidised BIM software/hardware, wireless networks and the requisite up-skilling and training) could encourage people and organisations to adopt BIM. This 'subsidy' approach has been used in Singapore, now regarded as a leading country in BIM adoption (Tahrani *et al.* 2015) and proven to be effective per (Yuan and Yang 2020). This is quite different from a forced compliance method that, for instance, bans them from using pens, rulers and drawing boards. The subsidy aspect of nudge could be useful to SMEs in the AEC industry as implied by Ganah & John (2013) who found that 'added cost' reduces their profit margins, but government-driven incentives (e.g. tax rebate/relief) are indeed a prerequisite for them to embrace the BIM agenda. Even with the opt-out option of nudge, it is unlikely that SMEs would abandon BIM if or when they recognise they have been 'nudged'. The nudging concept would likely counteract a one-sided 'mathew effect' of rich getting richer and results in all nudged firms willing to implement higher BIM level.

3 Findings and Discussion

An array of different BIM adoption strategies as implemented by several countries (Table 1) are based on six categories suggested by Cheng and Lu (2015). The categories have been modified in this study to recognise government mandate in the "Initiator and Driver" category which is an enforced driver for BIM adoption in public sector projects because stakeholders have no choice (Porwal and Hewage 2013, Smith 2014).

Table 1: Role/Initiative of Government/Public Sectors in Promoting BIM Adoption (adapted from Wong *et al.* 2011, Cheng and Lu 2015, Tahrani *et al.* 2015)

Country	Organisation/ Committee	Role/Initiative	Public sector roles (category)
United States (US)	GSA	Collaborated with software developers to produce a BIM guide.	Regulators
		Launched numerous pilot projects to study BIM implementation for various uses.	Demonstrators
		Mandated IFC-based BIM for various building analysis and design.	Initiator - Mandate
		International collaboration with real estate partners (e.g. Finland's Senate Properties) to support the creation of open standards for BIM so that interoperability and seamless exchange of digital data can be supported.	Regulators
	National Institute of Building Science (NIBS)	Carry out research on BIM and oversee the development of open data exchange standards such as IFC and COBie as well as the National BIM Standards.	Researcher
	National Institute of Standards and Technology (NIST), Fiatech and the Construction Industry Institute (CII).	These organizations are governmental agencies that carries out research on BIM	Researcher
United Kingdom (UK)	BIM Task Group	Mandated the use of BIM for public sector projects starting for 2016	Initiator - Mandate
		Development of open standards to facilitate interoperability and data exchange to reduce barriers in this exchange.	Regulator

		Development of COBie drops to allow public owners to validate the information received from their project team in a structured manner.	Regulator
		Reporting and promoting BIM by developing and monitoring activities such as forums, presentations, training, and workshops.	Demonstrator
	BSI, CIC, AEC-UK	Provision and development of BS series, AEC-UK-BIM Standard and AEC (UK) BIM Protocol.	Regulator
Finland	Tekes	Organised a public and private sector funding Pre-program at RYM for research and development of up to € 21.7 million for a period of 4 years between 2010 and 2014.	Funding agencies - Support
	Senate Properties	Require the use of IFC/BIM for its projects and provision of BIM standards and guidelines (e.g. COBIM).	Initiator - Mandate
Hong Kong	The Development bureau (DevB)	It has ordered the CSWP working group to monitor the development of BIM solution, and evaluate a time table for BIM to be incorporated into the current CSWP existing CAD standard.	Initiator - Mandate
		Encouraged a continuous monitoring and evaluation effort within the CWSP groups to determine a strategic plan to go in line with the emerging trends for BIM within the industry.	Regulator
	Housing Authority	Included BIM into its programme of activities for development and have been conducting investigation on some pilot project on how BIM can be used for improving design, operational efficiency and effectiveness.	Initiator - Mandate
	The HKIBIM	It established various committees for promoting and BIM implementation and providing a platform to aid the communication of different stake holders of BIM	Initiator – BIM activities and committees
Singapore	Building Construction Authority (BCA)	Public sector funding BIM fund to cover up to 50% of costs associated to BIM adoption within firms (12 million SGD)	Funding agencies - Support
		Provision of BIM standards	Regulator
		Reporting and promoting BIM by developing and monitoring activities such as forums, presentations, training, workshops	Demonstrator
Australia	BEIIC, AMCA, NATSPEC	Require 3D BIM for Gov. projects by 2016. BEIIC implemented BIM plan and pilot projects also, AMCA BIM initiative includes BIM forums and training plans NATSPEC have been working on the provision of National BIM Guide (e.g. ANZRS)	Initiator – Mandate
Denmark	*Det Digitale Byggeri*	The *Det Digitale Byggeri* is a public-private initiative by the Danish government; they have been providing series of requirements governing the use of BIM and ICT for consultant and contractors.	Regulator
	DECA	International collaboration with the GSA (USA) and Statsbygg (Norway) in 2008 to support open BIM based on IFC for BIM so that interoperability and seamless exchange of digital data can be achieved.	Regulator
	Palaces & Properties Agency	Require BIM on projects, organised BIM pilot projects and provision of BIM standards and guidelines e.g. 3D CAD Manual 2006	Initiator - Mandate
Norway	Statsbygg	Public and private sector funding for research and development (R & D) of up to € 21.7 million for a period of 4 years between 2010 and 2014.	Funding agencies - Support
		International collaboration with the GSA (USA) and DECA (Denmark) in 2008 to support open BIM based on IFC for BIM so that interoperability and seamless exchange of digital data can be achieved.	Regulator

From the examples (Table 1), it is clear that not all initiatives rely on forced compliance. Tahrani *et al.* (2015) showed that a 'BIM fund' was introduced by the Singapore government to support training, consultancy services, as well as the purchase of hardware and software. This is in addition to 'Demonstrator' projects that have also been used in USA and UK and the use "Funding agencies –

Support" in Finland and Norway. Other categories of public sector roles that might qualify under non-forced compliance initiatives are 'Researcher' and 'Regulator' (Tahrani *et al.* 2015; Wong *et al.* 2011). However, the nudge concept of policy implementation is not free from criticism as highlighted by Wells (2010) who argued that architecting choices may lead to unintended consequences since individuals tend to react unsympathetically to having their decisions being 'manipulated'. This is regardless of the benevolent principles behind whatever they are being nudged towards. Therefore, techniques of nudge tend to work best when users are 'unaware' that their behaviour is being influenced by choice architects because the desired outcome of nudging could disappear if nudging is recognized (Hansen and Jespersen, 2013; Selinger and Whyte, 2012). The temptation might be to 'disguise' a nudge but Thaler and Sunstein (2008) advocated for transparency in the process through the 'publicity principle' (Hansen and Jespersen 2013). This principle emphasises the *benevolent standpoint* that forbids governments from considering a policy they would not be able/willing to defend publicly to its own citizens. Hence, a government wanting to successfully nudge the industry towards BIM should be legally and ethically prepared to defend its discreet approach if or when stakeholders discover the strategy. Other critics of nudge theory (Selinger and Whyte, 2012) claimed that it does not always yield promising results as 'hyped' by the proponents because they could go wrong or may be ineffective. Consequently, Rayner and Lang (2011) have maintained that since more regulation (e.g. mandate) will not be any better either, improved information and effective communication can help nudge-driven policies achieve desirable outcomes.

This review conducted suggests that neither of the two strategies (i.e. mandate and nudge) would be ideal or self-sufficient on their own and further reflection is required regarding the possibility of merging them. This study thus takes the position that although contemporary BIM adoption strategy in countries like the UK is mandate-driven, the longer-term view for other countries could be to combine mandate and nudge.

4 Conclusions and Further Research

This study was aimed at understanding how competing BIM adoption strategies could lead to the achievement of a macro-scale adoption in the AEC industry. The study's focus is to critically examine the predominant BIM implementation strategy from the perspective of macro scale adoption in the AEC industry. The study argues that the predominant strategy used in developed countries (i.e. BIM mandates) is effective to an extent, but does not address all the challenges/problems of BIM technology diffusion in the AEC industry. Therefore, other strategies like nudge should be considered to complement mandates to realise the desired outcome of a holistic acceptance of BIM by all AEC organisations irrespective of sub-sector, size and geographic location. Nudging through subsidies and incentives was shown to be a suitable compliment to mandates and should be combined and used concurrently. Both strategies have their strengths and weaknesses and combining them will enable them to complement each other, possibly minimising their identified individual weaknesses. Hence, change agents should consider implementing such combined strategies to speed up the rate of adoption and for the process to be all-inclusive and sustained in the long term, especially for developing countries looking into a macro-scale BIM adoption.

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BIM in Facilities Management. Has COVID-19 Widened the Gap between Academia and Practice? A case study from Dubai.

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Abstract

BIM has attracted the attention of researchers over the past 2 decades. More recently, BIM in FM has started to get the attention of academics. However, the adoption of BIM in FM is still a puzzle, particularly in developing countries. This study aims to investigate the gap between research and practice, and the subsequent impact of the COVID 19 pandemic using Dubai as a case study. The study used a mixed-methods approach with a survey of the challenges rolled out to a random sample of 300 practitioners building on a set of challenges identified from the literature. The statistical analysis applied to the data gathered from 143 responses indicated the significant lack of awareness among practitioners. This was confirmed during the 10 interviews conducted with practitioners. The factor analysis identified two principal components for the challenges; the technical side and the resistance to change. The findings of the interviews indicated that many universities do not offer BIM training not to mention BIM for FM at the undergraduate level. The required initial investment in IT infrastructure and capacity building was another major challenge. The study found that Covid-9 has hit the sector hard thus holding any initiative that required investments. It was concluded that the education sector both universities and further education should introduce BIM practical training as a core component at undergraduate level courses. This will facilitate the adoption of BIM in FM saving the industry time and cost and should enhance the employability of graduates.

Keywords

BIM, Challenges, COVID 19, Education, FM

1 Introduction

Building Information Modelling (BIM) is defined as an approach for sustaining and applying a digital form of the project data throughout its lifecycle (Gu & London 2010, Shen *et al*. 2010 Miettinen & Paavola, 2014, Miettinen, *et al.* 2018). BIM has been increasingly adopted during construction projects forging the design and construction practices and adjusting to the new system. BIM is intended to support the entire project life cycle including the facilities management (FM) phase. However, BIM-enabled FM remains in its infancy and has not yet reached its full potential around the globe and in the UAE (Chan, 2014). The FM stage that includes the operation and maintenance could increase the total life cycle cost of an asset drastically. Previous studies indicated that the whole life cycle cost of a project is 5 to 7 times greater than the initial investment costs and 3 times more than the cost of construction (Government Soft Landings UK 2016). According to National Institute of Standards and Technology (NIST), the lack of interoperability among the various applications from design and construction to FM in a building's lifecycle cost $12.8 billion, out of which, $8.6 billion (2/3) is attributed to FM phase (Gallaher 2004). Most of the information passed to FM after completion of construction comes from 2D drawings, as built documents and redundant paper document system. The handover usually takes several weeks until the FM professionals can be satisfied that they received up to date and full set of documents. NIST reported that much of the building's valuable information is lost during the handover, which leaves FM professionals in chaos. Undoubtedly, the prevailing wave of digital transformation has recently witnessed notable developments catalysed by the emerging disruptive technologies that have been harnessed in various applications in the construction sector. Facilities management (FM) comprises a cluster of multidisciplinary activities which require extensive information storage, monitoring and management systems. The current Computer Aided Facilities Management (CAFM) systems which are used sporadically in the UAE address some of these needs yet are not fully synchronised with BIM. Previous studies indicated that Implementing BIM would provide the FM practices with functionalities of visualization, analysis and control that other FM information systems would not (Becerik-Gerber *et al.* 2012).

The review of the literature can depict a range of contributions to the practice by researchers across the globe, over the past two decades, emphasising the efficacy of employing BIM for FM. However, several studies indicated that the industry is clearly lagging behind by miles (Salama & Salama, 2019); to the extent that a number of studies repeatedly discussed the challenges, enablers and approaches that the sector should consider in order to accelerate the adoption of BIM in FM (Motawa *et al.* 2004 Mihindu & Arayici 2008, Arayci *et al*. 2012, Becerik-Gerber *et al*. 2012, Love *et al.* 2014, Motawa & Almarshad, 2015; Miettinen et al, 2018 and others). So far, there is no evidence from both the literature and the industry that this gap between academia and practice has been narrowed down. On the contrary, the COVID-19 pandemic has had a significant impact on the construction and real estate sectors with millions of jobs lost, globally and regionally. In the USA in just one state, NH, almost a million job were lost by June 2020 (Currie 2020). And in the UAE, one the key construction firms has gone into liquidation leaving thousands of workers redundant while struggling to pay their end of service and gratuity. The case is even worse with SME's (Nair 2021) and other key players that includes developers, contractors and property management firms. The purpose of this paper is to reveal the level of awareness of FM professionals on the implementation of BIM in FM, identify and rank the key variables, challenges & barriers, and explore the current and future level of commitment of BIM in the FM industry in the UAE amid the COVID-19 pandemic.

2 Literature Review

This section of the paper aims to provide a review of the literature with emphasis on the development of applications of BIM in FM and how the industry is adopting the output of academic research. BIM is a database technology that can store the visual, dimensional, and physical aspects of a building thus offers the ability to track and store the attributes of the different components within a building, to facilitate the exchange of information between the different project teams during the project lifecycle. (IFMA, 2013; Wang, et al., 2018; Eastman, et al., 2011). Most FM information systems, require entering data manually into the CAFM system after hand-over of the building. This task has proved to be laborious, time consuming and inefficient. By implementing BIM, the initial data needed would be available upon request and enhances the overall FM function through its advance visualization and analysis capabilities. BIM application has developed from automated cost estimating, virtual prototyping and the sharing of information to focusing on using BIM for energy analysis, sustainable development and maintainability checking (Becerik-Gerber, et al., 2012; Eastman, et al., 2011). However, BIM in the architectural, engineering and construction (AEC) industry has been more extensive than in the FM industry. The reliability of the data held is a vital aspect of FM that may cause havoc if it is not managed diligently. BIM was claimed to offer facilities managers an accurate and efficient method of storing, retrieving, and managing information (IFMA 2013). Developing models and tools for the handover process has become an important landmark in the development of using BIM for FM. In 2014, when BIM data were created and used in the facilities services in the University of Washington, USA, researchers believed that the idea of a single central BIM was a big step and may remain unrealised for the foreseeable future (Anderson, et al., 2012). Love et al., (2014) developed a framework for assessing the benefits of implementing BIM for FM based on the resource-based theory of organisation whereby asset owners seek value from their investment in BIM. Yet measuring the value of an IT investment remains subject to considerable debate. The cornerstone of the proposed framework was governance, performance measurement, change management and stakeholder management (Love *et al.* 2014).

Knowledge and knowledge management is a critical resource for any construction management (CM) and FM company as the built environment is a knowledge intensive industry (Ofek & Sarvary 2002). BIM enhances knowledge management and facilitates data sharing and retrieval among stakeholders (Motawa & Almarshad 2013, Motawa & Almarshad 2015, Wang, *et al.* 2018). The capture of visual and numerical data can benefit the FM teams during the operations and maintenance stage. BIM can create customised parameters of data (Kassem *et al*. 2015) thus enabling users to add and share knowledge related to specific building objects and guides the FM team on operations and maintenance activities (Wang *et al.* 2018). Previous studied extolled customised parameters within a BIM model whereby reliability, reduced redundancy of data, improved knowledge management, easier knowledge retrieval and more efficient knowledge sharing were highlighted as key advantages of using BIM. (Deshpande *et al.* 2014)

Facility Management (FM) entails the responsibility for: "the safe operation and maintenance of a corporation or organization's real estate as well as its systems" (Levitt, 2013). The range of the FM/operations and maintenance (O&M) activities contribute significantly to the costs during the building's whole lifecycle (Pereraet *et al.* 2016). According to the figures published by the International Facility Management Association (FMA), 57.5 per cent of total cost occurs during the FM phase (Teicholz 2013). The value of integrating BIM for FM resides in the inherent capabilities of BIM in capturing, storing and sharing accurate and comprehensive information about building elements and systems from pre-design project stages to post-construction stages (Becerik-Gerberet *et al*. 2011, Shalabi andTurkan 2016, Terrenoet *et al.* 2016, Pärn and Edwards 2017, Pärnet *et al.* 2017). Empowering facilities managers with such useful building information is crucial in reducing errors in retrofit planning and deconstruction, and minimizing risks in emergency management, while eliminating reactive maintenance within the O&M phase of constructed facilities (S. Neda Naghshbandi 2016). BIM lessens the incidence of data loss when handing over building facilities from the construction team to the FM professionals (Eastman 2011, Levitt 2013). Reduction of energy and space management costs, smoothed integration of systems and higher building performance are ubiquitously quoted as tangible benefits of integrating BIM into FM practices (Teicholz 2013, Volk et *et al.* 2014, Alwan 2016, Shalabi and Turkan 2016). Other benefits are related to the maintenance of warranty and service information, quality control, enhanced monitoring, emergency and retrofitting management and occupancy planning (Volk *et al*. 2014; Gheisari and Irizarry, 2016). Furthermore, by integrating BIM with augmented reality, members of the FM are able to interact with buildings with more visualization to handle the operation & maintenance tasks (Volk et al., 2014).

BIM is mandated in the USA, UK and some European countries whereby Finland, Denmark, Norway and Sweden are considered as the BIM leaders in the world (Arayici, 2012). Miettinen et al., (2018) found that almost all large contractors in Finland used BIM for design and construction. However, the FM practitioners indicated the need for the further development and integration of the FM information systems. BIM was recognised as a potential future technology, however, they found it difficult to specify how BIM could enhance current practice. Awareness and knowledge have been highlighted as one of the biggest setbacks of BIM implementation in FM (Miettinen, et al., 2018). In south Asia, for instance, Singapore has been promoting BIM since 1997 where currently it is required for various aspects in construction such as building plan approvals and fire safety certifications (Wong, et al 2009). In Hong Kong, although BIM is being implemented, it is still considered in its early stages (Chan, 2014). The owners tend to prioritise adopting advanced technologies for the design and construction activities while research had proven that the costs incurred during the FM phase are significantly higher. (Irvine, 2018). Most recently, Pidgeon & Dawood (2021) studied the benefits of integrating BIM with IoT to address what they called the disadvantages and inefficiencies in the adoption of BIM in infrastructure projects and asserted that there is a gap between academia and practice

"There is also evidence of a disconnect due to both the overwhelming nature of BIM (acronyms, competing standards and technology) in that people are unsure what to implement and when, with a lack of objective focus on what the goals and advantages at a project level." (Pidgeon & Dawood, 2021)

Apparently, after almost two decades of research output on the application of BIM in the design and construction phases, the industry is still lagging in adopting the various models and frameworks delivered by the academic research community. Evidently, the research output on BIM in FM is comparatively at an infant stage compared to the studies conducted on the design and construction phases. This was the main driver that enticed the author to embark on this study, primarily, to investigate the level of awareness of BIM in FM, the current practice in FM in Dubai, and to what extent the COVID-19 pandemic has impacted the adoption of BIM in FM.

3 Research Methodology

The set objectives of the study suggested that a deductive approach was appropriate to verify and rank the list of challenges identified from the literature. However, it was resolved to follow a mixed methods approach whereby the survey would be followed by a set of interviews with experts that is primarily seeking insightful depth about the impact of COVID19 on the implementation of BIM. In addition, the interviews aimed to validate and further explicate the findings of statistical analysis applied to the survey data (Creswell, 2009). The survey used a questionnaire that was constructed based on the list of challenges identified from the literature. In total, there were 11 factors listed as challenges as shown in Table 1. The questionnaire was divided into two sections; section one included profile information about the qualifications; profession; Familiarity/experience with BIM. Section two asked participants to rank the challenges identified from the literature according to the importance (severity) on a scale of 0-10 where 5 indicated "do not know/can't decide" as a neutral point and 0 indicated very low importance whereas 10 indicated a very critical challenge (Carifio & Perla 2007). A random sampling approach was used to send the questionnaire to a mailing list of 300 professionals: IT specialists and project/facilities managers. The survey attracted 143 responses, i.e., a response rate of 47.7% (> 40%). On the other hand, the semi-structured interviews utilised a purposive sampling approach and targeted experts in facilities management with knowledge about IT, in UAE. The interviews were mainly seeking to validate and explicate the findings of the survey. Fifteen interviews were planned. However, only ten interviews were conducted due to the COVID 19 restrictions, out of which two interviews were in person and eight were administered via virtual meeting. The participating experts were asked to fill in the survey questionnaire in advance and return it before the meeting. The interviews were conducted after the survey which allowed for the comparison between the scores provided by the experts and the outcome of the statistical data analysis of the survey data set. During the first segment of the interviews, experts were asked to shed light on the ranking that resulted from the statistical analysis of the listed challenges. The second part of the interviews focused on the impact of COVID19 on the sector in general and the adoption of BIM in FM, in particular.

4 Findings and Discussion

The survey data collected from random sample of 300 practitioners in the field of construction and facilities management attracted 143 responses which were tabulated and the scores for each question were examined. Notably, the data analysis identified the high frequency of the neutral score that is 5 which refers to the "cannot decide" category for both challenges and enablers factors listed in the questionnaire. The frequency for score 5 for the11 challenges ranged from 61-72 out of the 143 responses. It was resolved to start by cleaning the data i.e. to examine the data set without the influence of the score 5 that can skew the mean score or at the least will affect the dispersion of the data because the mean will appear more clustered around the neutral score (5). Following the treatment of the data (filtering out score 5), the mean scores for the challenges were calculated based on the received scores for each factor, excluding score 5. The means for the challenges are shown in table 1.

Table 1. List of Challenges ranked based on the mean score (143 responses)

SR	Challenge	Mean
C7	Cost verses benefit (profitability)	7.39
C11	Information and interaction constraints	7.17
C10	Security against cyber-attacks for this digital infrastructure	7.17
C8	ICT infrastructure (storage, real time data transfer)	7.11
C6	Lack of awareness leading to lack of acceptance	7.09
C3	Resistance to change	6.96
C4	Lack of clarity in addition to the perceived immaturity of the technology	6.84
C2	Technical challenges	6.76
C5	Perceived Time lapse (time needed to adapt and implement)	6.66
C9	Lack of relevant skills	6.66
C1	Absence of centralized regulatory body/system (mandate)	5.94

4.1 Discussion of the findings of the survey statistical data analysis

The most compelling finding of the statistical analysis is the apparent lack of awareness emphasized in the high frequency of score 5 "cannot decide" category. This has been in line with the ranking of the Challenges C6 which attracted relatively high score 7.09. This is a critical factor that needs attention from various stakeholders (Larios-Hernández, 2017). The ranking of the challenges indicated that the top three challenges are C7, C11 and C10, respectively as shown in table 1. These refer to the cost benefit ratio, the security concerns and interaction between key stakeholders within the food chain. To elaborate further on these critical factors in sequence, on the one hand, it is imperative that without clearly perceived benefits from shifting to BIM in FM, it will be hard to drive the change (Yeoh, 2017). Cost has been emphasised as the most critical factor during the interviews as well. During the COVID 19 pandemic, the sector in general has been under enormous financial pressures. On the other hand, the security factor is a major issue with the technology, in general, due to the exposure to cyber risks that can jeopardize organizational confidential data (Hendricks, 2016; Yeoh, 2017). It is reasonable to say that the lack of awareness as indicated by the prevalent score 5 would magnify the impact of the security concerns as rooted in the risk management theory whereby seeking more information is recommended as a risk response strategy in the case of ambiguous scenarios (Haniff & Salama 2016). The third factor relates to the structure of the sector in Dubai in the context of BIM which is seen as an ecosystem that needs key stakeholders to join forces in order to give this initiative a sustainable kick-start. This is analogous to other applications of the advanced technology. It can only gain momentum when all key players buy into the applications in order to start sharing thus reaping the benefits. The aforementioned two challenges coupled by the dire economic conditions amid the COVID19 that has featured in the job losses and delayed payments (Nair, 2021) has impacted the digitization of the sector whereby priorities do not seem to favour such transition that will require initial investments and capacity building, at least until the economic conditions improve.

4.2 Factor Analysis for the Survey Data

Due to the relatively high number of the challenges, it was resolved to explore the possibility to reduce the data into meaningful factors. The KMO and Bartlett's Test indicated the appropriateness of the technique with values > 0.8 (Hair, et al., 2010). The factor analysis applied the principal component method and varimax technique for the rotation of axes to ensure orthogonal factors. The analysis yielded two principal components as shown in table 2. The findings of the factor analysis were congruent with the findings of the statistical analysis and provided meaningful reduction of the data into two components for the challenges: the Technical/Security and the Resistance to Change which is also in congruency with the literature (Deshpande *et al.* 2017, Boulos *et al.* 2018 & Iansiti & Lakhani 2017). The variables under the Resistance to Change component included the anticipated cost (initial investment), the lack of awareness, the natural resistance to change and the lack of skills. The variables under the technical component included the explicit technical concerns such as the IT infrastructure and the security issues. C1 that reflected on the role of local authority being amongst the least critical challenges is a positive indication that indicated confidence in the local authorities to play their anticipated role. C5 and C9 that reflected on the time needed to adapt and the lack of skills, respectively. The score of 6.66 indicated the relatively higher perceived importance of other variables (score > 7) such as cost, IT infrastructure and security, in addition to the lack of awareness.

Table 2. Principal Components

Principal Components - Challenges	
Technical	Resistance to Change
C2	C3
C1	C4
C5	C6
C8	C7
C10	C9
C11	

4.3 Discussion of the findings of the Interviews

The data collected was analysed using thematic analysis whereby the relevant themes guided by the set objectives were identified in the primary data set while maintaining a positivist deductive approach (Clarke V & Braun V 2013). The findings of the interviews shed more light on the outcome of the statistical analysis. Overall, participants were not surprised to know about the sheer lack of awareness portrayed by the high frequency of score 5 (cannot decide). Three out of the ten participants declared that they heard of BIM but they cannot claim that they are aware of how it works. The same group were not also aware of CAFM. They (like many others in the industry) practice FM under the umbrella of property management which includes valuation, leasing and other related activities. FM according to this group is reduced to maintenance, primarily to respond to their tenants' claims, and typically outsourced to a third party. Participants confirmed that this is the prevalent practice in the case of residential buildings, particularly villas that are owned by individuals who hire a property management agent to take full responsibility of the property. In most cases, tenants who rent properties that fall into this category would not see the landlord and when they need maintenance, they would call the third part directly. The latter would normally seek approval from the agent to ensure that the subsequent invoice will be paid. There is no evidence that the humble service provider (the third party) who is typically a plumber, electrician or a painter and decorator has access to any building information and more than likely has no idea about the concept of modelling! In many cases, the more sophisticated works like the air conditioning is outsourced to the company who supplied and installed the system using a service level agreement. This was an interesting finding that explained the current practice, and according to the common view amongst participating experts this applies to a large sector within the existing residential building stock. The second category included residential and commercial buildings that belong to large scale developers who would typically have an FM arm. The interviewed experts indicated that only a few very large-scale developers are using BIM in the design and construction phases and fewer are using CAFM for the FM phase. This is more than likely to be in the case of government projects as it is mandated by the government. Consistently, all interviewed experts confirmed that they are not aware of any application of BIM in FM in Dubai. An interviewed expert working for one of the banks confirmed that they do not even use CAFM. This verified and validated the findings of the survey data analysis that indicated the low level of awareness of BIM in FM.

The next theme that emerged was the key challenges and main deterrents as perceived by the interviewed experts. The Dubai real estate market seems to be a short-term venture with most of the investors are there for the short haul unlike other markets in the UK, US, and Canada (Salama and Al Saber 2013). It is more of a buy to flip market, and profit maximisation is the main goal for all stakeholders. For example, it is very rare to see Apartment Owners Association (AOA) in Dubai because most of the occupants are tenants and not landlords. This was one of the main obstacles that slowed down the implementation of the green building initiative in Dubai for more than 4 years until it was imposed by the government in 2012 (Salama and Al Saber 2013). The economics of the construction and property sector in Dubai is quite unique and is significantly affected by the demographics of the country whereby over 80% of the population are expats whose residency is function of their employment thus the majority are unlikely to commit to long term investment in property. Needless to mention that for expats who represent the demand side in the market, cost is paramount. The fluctuations in the rental value for the same property over the past 15 years in Dubai is the best example to illustrate the special nature of this market. This is mainly driven by the level of economic activities and the state of the economy. In some upmarket districts in Dubai, the same property was leased in 2021 for 35%- 45% of the lease value in 2005/6 despite being in immaculate condition (Sajan 2021). This impacted the lease value for the new units due to the market dynamics. Considering the significant rise in the cost of building over the period of 15 years, developers will

undoubtedly be seeking cost reductions. This explains and further verifies the findings of the survey data where cost was identified as the most critical challenge towards implementing BIM in FM.
Another critical theme that emerged from the analysis of the interviews data was the natural resistance to change that would be driven by other factors besides the cost. Amongst the most critical impediments mentioned by the participating experts were two factors. First, the need to have an integrated system where the key stakeholders would be enticed to implement BIM because of the nature of BIM that requires participation throughout the supply chain and in real time (Pidgeon & Dawood 2021). This ties well with the technical component identified by the factor analysis. The second factor was the readily available skills that would facilitate and expedite the transition. This does not seem to be the case. The general view suggested that both higher and further education are not delivering the goods. One of the interviewed experts who is a visiting professor in one of the international universities in Dubai could not identify any practical BIM courses/modules at undergraduate level offered by his institution where students learn and train on how to use BIM software, and asserted that this is the case in most of the universities in Dubai. This finding raises the question about how integrated the research and teaching and learning activities are in higher education and particularly in FM. With the flux of research on BIM over the past 20 years it is odd that some universities still do not offer BIM training as a core component in construction and FM undergraduate degrees. The notable comment by one of the interviewed experts when asked about the perceived gap between academia and practice was that it seems that the gap is between academia and academia! Apparently, the higher education sector has a significant role in driving the shift towards digitised FM by sending to the market qualified and well-trained graduates who are willing and able to implement BIM in FM. This should help in reducing the training cost, the capacity building time and the subsequent cost of time.
When asked about the impact of COVID 19 pandemic on the implementation of BIM in FM, the participating experts had different views. One the one hand, some were convinced that regardless of the pandemic, the sector in Dubai is not ready to adopt BIM in FM due to all the above-mentioned factors. On the other hand, the alternative view was that the sector has been in dire condition for almost 18 months, and it is uncertain when things will get back to normal. Only then, the real magnitude of damages will be assessed, and the appropriate recovery plans will be devised. It might be a golden opportunity to introduce a paradigm shift guided by the advanced technology. However, for this to happen, the essential pre-requisites need to be readily available. First, the government has to impose the appropriate regulations as was the case with BIM in construction: Appropriate regulations that take into consideration both the new stock of buildings as well as the existing stock. The latter will be more challenging, yet the current practice is far from being sustainable, so actions are needed. Second, universities should lead by example. Utilising some of the available capacity in providing practical modules/training on the BIM application for FM so that the graduates would act as facilitators and active ambassadors that would take the lead in shaping the practice. A combination of external factors (regulations) and internal drivers (trained young practitioners) coupled by the development in the technology that may reduce the initial investment in IT infrastructure, all these factors together may change the playing field towards a more sustainable practice.

5 Conclusions and Further Research

The aim of this study is to investigate the gap between research and practice in the context of BIM in FM and the subsequent impact of COVID 19. The statistical analysis of the survey data followed by the data reduction using principal component analysis yielded two principal challenges, the technical challenges, and the resistance to change. The former reflected on the required integration across the food chain as well as the IT infrastructure. The resistance to change reflected the concerns about cost as well as the impact of market dynamic and the economics of the sector. However, the lack of awareness was the most significant challenge. After almost two decades of research on BIM, the lack of awareness indicated that there is significant gap between academia and practice. This further explains and verifies what other researchers have been referring to (Pidgeon & Dawood 2021). The education sector (higher and further education) has to address this gap by instilling BIM training in CM/FM courses. This will help dampening other impeding factors such as cost of training and capacity building and the time required for both. Indeed, cost is a key challenge and the COVID19 pandemic has hit the sector hard thus slowing down any initiatives that would require initial investment. This findings of this study should help academics who are designing CM and FM curricula to improving the quality of their graduates thus enhancing their employability.

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Barriers to effective digital leadership enactment in the construction industry

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Abstract
This study considers the role of leaders in driving digital transformation in their organisations. Considering that the construction industry is slow at adopting digital technology, the aim of the study was to explore the factors that inhibit leaders from driving digital transformation in their organisations. Data was collected through a qualitative questionnaire survey. Participants were asked to describe barriers to effective digital leadership in their organisations. The issues that hinder effective digital leadership were grouped under five themes: leadership characteristics, management and organisational issues, resource constraints, technological issues, and risk perceptions. The study shed light on the barriers to digital leadership enactment in the construction industry, an issue that has received limited attention in the existing literature. The findings are useful to business leaders, researchers, trainers and educators to develop measures to encourage leaders in the industry to be at the forefront of digital transformation in their organisations.

Keywords
leadership; digital leadership; digital transformation; digital innovation

1 Introduction

Construction is one of the prime sectors of the UK economy, contributing almost £90 billion to the local economy (or 6.7%) and comprising of over 280,000 businesses. Although described as the most complex and adverse, the industry accounts on average for about 3 million jobs, equivalent to 10% of total UK employment. The industry is globally set to grow by at least 4.3% until 2025, according to the 2025 strategy report (BIS UK, 2013). It is suggested that at the heart of the construction industry's future is the need for digitalisation.
Digitisation is driving rapid transformation in many sectors like healthcare, banking, manufacturing and finance (Hoar et al., (2017). However, this transformation is occurring at a much slower pace in construction (Boon and Prigg 2012). Business leaders and managers can play a crucial role in influencing their organisations to speed up digital transformation. Therefore, it is vital that leaders in the construction industry be seen to be at the forefront of their organisations' endeavours to digitalise. The influence of leadership in driving innovation in organisations is well documented. However, there have been limited studies dedicated to the role of leadership in driving digital innovation in the construction industry (Zulu and Khosrowshahi, 2021). Therefore, this research aimed to explore factors that impact digital leadership enactment in the construction industry.

The study is based on an exploratory qualitative study. Data was collected through a qualitative questionnaire survey to afford a relatively large sample size to provide free-text responses to several questions focusing on addressing the research purpose. Data were analysed using an inductive thematic analysis approach. The barriers to digital leadership enactment were grouped under five themes: leadership characteristics, management and organisational factors, resource constraints, technology, and risk perceptions. These are discussed in detail in the findings section.

2 Digital Leadership

It is projected that digitisation will influence the organisational process in 93 per cent of construction firms (Russo 2016). Oesterreich and Teuteberg (2016) opine that the influence in the construction industry will be driven by factors such as robotics, automation, integration of sensors and increased use of social media platforms in construction firms. For example, the one trillion sensors connected through the internet can allow for a significant digitisation escalation predicted for the next five years (World Economic Forum 2016).

Adesi et al. (2018) identified 12 drivers, including their perceived advantages that will arise with implementing these technologies. Results highlighted that companies were mainly motivated by process improvement and demands communicated by their customers. Similarly, a clear understanding of the factors influencing the implementation of digital technologies in construction is necessary; but has not been widely researched. However, executives might be interested in measuring the successes of digital initiatives. Without first understanding the awareness of what drives success factors forward, it will be challenging to influence success targets.

The term “digitisation” refers to the application of digital technologies to connect people, devices and data to improve and transform business processes (Bughin et al., 2017). Much misunderstanding, however, exists about the term “digital transformation”. Initially, the term seems to have focused on an ultimate shift in the way organisations think, work, and manage digital trends responses in competitive markets (Kane, 2017). However, conceptualising digitization should be regarded as an ongoing process for growth and development that may help managers during digital adolescence (Kane, 2017). Gartner describes digitalization as the new era for enterprise IT, where IT and business innovation are more integrated and corporate IT shifts to digital from a legacy perspective—emphasizing the need for digital leadership. He further uses tenure to explain the process of using digital technology for enhancing business models and value-created opportunities to move to digital business (Gartner, 2016).

The role of leaders is considered to be critical in driving digitalisation, hence the term digital leadership. An increased level of engagement from those in transformation-specific roles and senior leaders has been pointed out as a critical determinant for success, according to the MIT (2014). Chung et al. (2005) and Qiping Shen et al.,2003) also highlighted that lack of management support is a significant barrier in the DT process. Based on previous studies, there is a clear requirement for what constitutes effective digital leadership, what capabilities are needed and how the fundamentals of digital leadership can be built upon and strengthened. El Sawy et al. (2016) defined digital leadership as “Doing the right things for the strategic success of digitalization for the enterprise and its business ecosystem”, borrowing concepts of Bennis (1989) definition of leadership that “leadership is about doing the right thing for the success of the organization, while management is about doing the thing right.”

Hoar et al. (2017) argue that there is a real need for digital leadership in the Industry. Considering that the construction industry is slow at adopting digital technologies, the role of leaders should be investigated. Furthermore, Accenture indicates that 75% of obstacles hindering digital transformation are non-technical factors (Accenture,2016), suggesting that DT is less about technology and more about transforming individuals. Similarly, Kane et al. (2019 and Anghel (2019:38) argue that digital transformation is less about technological aspects than it is about managing the transition, including effective leadership, acquisition of appropriate skills leaders, managers and employees to buy-in and integrate the organisation's systems with the new digital technologies.

Past research has centred mainly around describing the technical implications of digital transformation. Nevertheless, there is little research available that deals with digital leadership within the construction industry within the UK. Therefore, the purpose of this study was to explore factors that impact digital leadership enactment in the construction industry.

3 Research Methodology

Data was collected using a qualitative questionnaire survey, where respondents are asked open-ended questions and are required to respond with free textual data, are uncommon. Braun, Clarke and Gray (2017, pp 15) suggest that "the method is suitable for exploring people's experiences and their practices, perceptions and understandings about the research topic, and researching sensitive topics". This suited the present study, which sought employee perceptions of their leaders' attitudes towards digital innovation to avoid self-reporting bias if leaders were asked to evaluate themselves. A convenience sampling approach was adopted to identify suitable participants. The study involved asking students studying part-time construction-related master's courses at a university as a study population to complete the questionnaire. Convenience sampling in qualitative research is mainly used where study participants are conveniently accessible concerning access, location, time and willingness (Lopez and Whitehead, 2013).

The data were analysed using the inductive thematic analysis procedure described by Hayes (2000). There are two primary ways in thematic analysis for identification of themes within data. One can take either an inductive or 'bottom up' way or a theoretical or deductive (Haye, 2000). In distinguishing between the two approaches Braun and Clarke (2016) characterise an inductive approach as one where the coding of the data is data-driven and does not try to fit it into a pre-existing coding frame, while a deductive/theoretical approach as one which is driven by the researcher's theoretical or analytic interest in the area. An inductive approach was used in this study without considering the typical categorisation of leadership in general literature as the authors wanted to provide a characterisation of leadership based on first-hand experiences of employees. The analysis approach also followed Braun and Clarke's (2016) six phases of analysis which included: familiarizing oneself with the data, generating initial codes; searching for themes; reviewing themes, defining and naming themes; and reporting.

4 Findings and Discussion

4.1 Sample Demography

Considering the purpose of the study, it was an inclusion criterion that participants in the study should have experience working in a construction industry organisation for them to be able to indicate their perceptions of digital leadership. Table 1 below summarises the characteristics of the sample. As can be observed from the table, while most participants worked in quantity surveying and commercial management, the participants represented various professional roles. Almost 80% were classified as professionals, first-level managers and middle managers, with less than 25% represented by trainee level participants. This was also reflected in the participants' experience in the construction industry, which shows that over three-quarters of participants had at least three years of experience in the construction industry, and a quarter had less than three years of experience. Thus, the data shows that the 38 participants were of a suitable profile and therefore were deemed suitable to inform the study of their perceptions of digital leadership in the construction industry. However, further analysis of data did not take into consideration the respondents' profiles.

Table 1: Sample Characteristics

Characteristic	Frequency	Percent	Characteristic	Frequency	Percent
Gender			*Years working in the construction industry*		
Male	14	37%	Less than 1 year	4	11%
Female	24	63%	1-2 years	5	13%
	38	**100%**	3-5 years	10	26%
Present Job Role			6-10 years	5	13%
Director	2	5%	Over 10 years	14	37%
Architecture and Design	8	21%		**38**	**100%**
Quantity Surveying & Commercial Management	16	42%	*Number of Employees in Company*		
Planning	1	3%	Less than 10	6	16%
Project & Contract Management	6	16%	Oct-50	6	16%
Engineering specialist	3	8%	50-250	9	24%
Other	2	5%	250-500	3	8%
	38	**100%**	Over 500	14	37%
Position in organisation Hierarchy				**38**	**100%**
Middle Managers	2	5%	*Company's Annual Turnover (Millions)*		
First Level Managers	5	13%	Less than £1M	7	18%
Professionals	23	61%	£1M-£2M	6	16%
Entry Level/Trainees	8	21%	£2M-£10M	9	24%
	38	**100%**	£10M-£50M	5	13%
Years in employment with company			More than £50M	11	29%
Less than 1 year	8	21%		**38**	**100%**
1-2 years	15	39%			
3-5 years	7	18%			
6-10 years	5	13%			
Over 10 years	3	8%			
	38	**100%**			

4.2 Barriers and enablers to digital leadership enactment

The purpose of the study was to determine the barriers and enablers to effective digital leadership in the construction industry from an employee's perspective. The analysed free-text responses using an inductive thematic analysis approach. Braun and Clarke's (2006) six phases of thematic analysis were followed in analysing the data and resulted in the identification of five themes. These include leadership issues, management and organisational issues, technological issues, resource constraints and risk perceptions. These themes provide an insight into the perception of participants of factors that impact on the leaders in their organisations in driving digital innovation in their organisations. The five themes are presented below.

Theme 1: Leadership characteristic influences

This theme reflects comments that described the characteristics of the leader that can impact on digital transformation. It reflected the leaders themselves. It is reflected under the following sub-themes: lack of motivation and drive; lack of training; resistance to change and traditional mindsets; and lack of leadership buy-in.

Participants reflected on the lack of drive and or motivation by their organisational leaders. For instance, P15 indicated that *"The main barrier in my view is the lack of motivation from the company leaders to push innovation and invest the time needed to make it a success"* (P15), while P18 characterised leadership in their organisation as: "*There is no drive from the company leadership towards digital transformation"* (P18). Another participant reflected on the need to modernise and the need for conscious leadership to drive innovation: "*Not with that momentum, which should be based on conscious leadership, as it should be realized that some of the technology currently used are from past, and more effective solutions must be sought to keep pace with the huge technological developments*" (P32).

Some participants reflected on leaders' resistance to change: "D*irectors being resistant to change (P22); very resistant (P20)*. Studies on resistance to change tend to focus on employees' resistance to change. However, the context here is that leaders can also be resistant to change even when employees are eager to change organisational practices and procedures. The traditional mindset is also seen to be a barrier to digital leadership enactment. For example, P24 commented: *"Traditional mindset takes time to adapt to changing circumstances",* while P14 stated. (there is) *"Old school management that sits at the top of the organisation".* The traditional mindset among leaders is not always universal across organisations. In some organisations with multiple departments or sites, this adoption of technology company-wide may be an issue. In some organisation, one department is eager and driving digital innovation, while in other departments, it is not the case. For example, P5 stated: *'Overall positive from leadership within the office. Within other offices, it appears that there is less of a drive to push the software'.*

Top management support is essential for successful change initiatives. Some of the responses reflected the lack of leadership buy-in. For instance, a participant indicated: "*Not every effective, there is a lack of buy-in from management"* (P21). P3 indicated, *"Our leaders have to be show more conviction in their leadership, there doesn't seem to be any drive-in digital transformation"*. Others indicated a lack of drive from the top and that digital transformation initiatives are driven by staff.

Theme 2: Management and organisational factors

This theme reflected management issues and organisational design influences on the leaderships ability or disposition to drive digital innovation in their organisations. Four key barriers were identified. These include lack of strategic focus, lack of training, change management procedures, communication and engagement, human resource issues, and management structure. Participants noted the lack of strategic focus to drive innovation. It was common to see descriptions of leaders who were focused on the 'business as usual' practices with little consideration of digital innovation. For instance, P29 indicated: *"Focus on profit generation and limited capacity to concentrate on the future"*. Others such as P7, P6 and P12 also reflected on management's focus on current achievement rather than the long-term investment.

Others reflected on the lack of training for both leaders and their team to drive innovation. For instance, P21 indicated "*Lack of training for the management and the rest of the firm*", while P26 reflected on the need for training: "*Need more training and more proactive to go with the trend*". Training can be an important factor to help leaders' transition from a traditional mindset to a new mindset fit for the digital age (reference). Effective change management processes were also noted as a barrier to digital leadership. For example, P4 was categorical in identifying this as a barrier to digital leadership: *One participant noted "lack of effective change management*" [P4]

A related concern was the inadequate or poor information flow within organisations. Some of the participant responses showed that management appeared not to have put in place a coordinated effort to digital innovation, as evidenced by poor communication. For example, one participant commented that *'... communication to people in non-leadership roles is poor. These people often don't find out about what's being introduced until it's happened, there are often many teething problems'.* [P16] while another: *'I find it is enforced with lack of understanding or direction leading to impatience and scepticism'.* [P25]. Internal communication is known to be a key factor in driving organisational innovation (Sklyar and Sokolova 2019). In particular, the quality of the information exchange can reduce the amount of uncertainty, improved organisational climate, and surrounding the project better cross-functional co-operation in organisations (Lievens, et al.,1999).

The organisation structure was also identified as a potential barrier to leadership enactment. For example, P3 indicated that *"The size of the organisation, budgetary constraints and too big a gap between the main people at the top and the day to day team leaders".* In some cases, the pace of digital technology adoption differs between departments within the same organisation. Form an entire organisation perspective; leaders fail to have a coherent approach to digital innovation. For instance,

> *Within my own organisation, there is a drive from some senior managers, but in the whole the digital transformation within the organisation is currently limited" [P15]*

Theme 3: Technological factors

Technological barriers related to three key issues including: leaders' understanding of technology know-how, organisational IT infrastructure and leaders' perception of the value of technology. The leaders' lack of understanding of the workings of digital technologies (technology know-how) was identified as a barrier to their ability to drive digital innovation in their organisations. For instance, P17 indicated that *"being of the older generation and doesn't really understand how the technology works" [p17].* The lack of understanding of how technology works is also seen to give leaders unrealistic expectations: *"Lack of their own understanding of the software giving them unrealistic expectations either in terms of deliverables or timeline" [P25].* Others pointed to the leader's lack of understanding of the value of digital technology. Some participants noted the need for an IT infrastructure to drive digital innovation. For example, P13 noted that *"We do not have an IT department, our Partners are Quantity Surveyors/Project Managers and, therefore, aren't always aware of the latest digital trend in the industry".* While P27 noted: *"Reasonably good, but we've struggled to move away from the use of xxx to xxx, generally most systems are online, run well the vast majority of the time, they did outsource IT support to an external company which hasn't gone too well".*

Theme 4: Resource constraints

This theme reflected the impact of financial and time pressures on the leaders' motivation to drive digital adoption. A related issue to cost pressures is the lack of investment capabilities within the organisations. The cost of the technologies was seen to be a factor influencing leaders to drive digital innovation. For example, P6 indicated: *Lack of understanding and the costs associated with a digital* *transformation [P6]*. Others reflected on the limited investment capability of their organisations as a factor influencing leaders' efforts to digitalise their organisations. *"Financial constraints" [P34] and "Lack of capacity to invest" [P12]*are examples of sentiments provided by the participants in reflection of factors that influence leaders' drive towards digital innovation. Another resource constraint factor related to time pressures. P5 stated, *"Not enough time to dedicate to learning" [P5]* while P12 indicated *"Lack of time to focus on digital strategy" [P12]*

Theme 5: Risk perceptions and attitudes

The risk perceptions and attitudes of leaders also seem to play a part in influencing their ability to lead organisations to transform digitally. The leaders' attitudes towards risk were recognised as a barrier to leaders' drive for digital transformation. Sentiments such as *"(un)willingness to take risks" (P27) and "Risk aversion and unwillingness to experiment" [P4]* reflected leaders risk attitudes towards digital innovation. Risk perceptions were also reflected in leaders' perceptions of uncertainty in outputs from digital technologies considered for adoption. For instance, P32 indicated: *"The uncertainty in the form of the output that may result from the use of this technology"*. Participants also reflected on the uncertainties in the return on investment (RoI). Below is an example comment from a participant:

> *"The main barrier in my view is the lack of motivation from the company leaders to push innovation and invest the time needed to make it a success. Understandably leaders need to see that any investment is commercially viable and until this is confirmed there will be a barrier to any development" [P15]*

5 Discussion

The use of the qualitative questionnaire enabled us to investigate the perceived barriers to leadership enactment required for digital transformation in the construction industry, an issue that has remained unexplored. The main findings are that the barriers to digital leadership enactment can be grouped into the five themes: leadership issues, management and organisational issues, technological issues, resource constraints and risk perceptions. Table 1 represents the key barriers to digital leadership based on the findings presented above.

Table 1: Barriers to digital leadership enactment

Categories of barriers	Factors
Leadership characteristics	Old school perspectives- resistance to change Leadership buy-in Lack of motivation and drive Ineffective leadership
Management and organisational barriers	Lack of strategic focus Change management Communication and engagement Human resources- training and skills Management structure- Management levels
Technological factors	Technology know-how IT infrastructure to drive innovation Lack of appreciation of value of DI
Resource constraints	Budgetary constraints Cost as an inhibitor- financial pressures lacking investment capability Time constraints
Risk attitudes and perceptions	Risk attitudes Uncertainty of outcomes Uncertainty- ROI

While we did not find a study that focused on barriers to digital leadership enactment in the construction industry, there are some similarities between our findings and issues identified in the literature on barriers to digital technology adoption. However, in these previous studies, the unit of analysis is mostly at an organisational level and not at the leadership level. We did not focus on leadership on an individual level but leadership as a collective from a distributed leadership context. In distributed leadership, rather than focusing on the work of individual leaders, it explores the interactions between a layer of leadership functions. Harris (2009) points out that distributed leadership recognises that there are multiple leaders and that leadership activity are widely shared within and between organisations. As such, distributed leadership focuses on the interactions, rather than the actions, of those in formal and informal leadership roles (Leithwood et al., 2007).

The characteristics of leaders is acknowledged in the literature as a vital element for innovation in organisations. See, for example, Cortellazzo et al. (2019), who concluded that leaders are key actors in developing a digital culture within an organisation. Studies such as Oberer and Erkollar (2018), Rukmani (2010) and Mkheimer (2018) have shown the impact of leadership characteristics on organisational processes and outcomes. The findings also identified the role of management and organisational factors that impact on the effectiveness of digital leadership enactment. The issues under this theme can be related to the elements in McKinsey's 7S model, which identifies seven organisational elements, including strategy, structure, systems, style, skills, staff and superordinate goals, where change can be evaluated. The idea is that organisational effectiveness stems from the interaction of the myriad of factors, some of which may not always be obvious. Waterman et al (1980) acknowledged the multiplicity of factors beyond mere consideration of structure and strategy. The McKinsey 7S model focuses on analysing organisational areas where change is expected to be made, while the other four models provide steps or processes required in managing organisational change. The McKinsey 7S model, therefore, lends itself well to be used as a basis for evaluating changes in the organisation as such was adopted for this study.

Technological barriers are have been shown to impact on digital technology adoption. For example, Somsen et al. (2019) identified lack of IT knowledge and dependencies of other technologies as barriers to BIM adoption. El Sawy et al. (2020) demonstrated a case study's analysis of the need for digital leadership to address five key elements, including business strategy, business models, enterprise platform integration, people mindset and skillset, corporate IT function, and workplace culture. The elements above include both organisational and technological issues. For example, Bradley et.al., (2015) in their study, contends that twenty-five per cent (25%) of executives believe that there are "high" barriers to digital disruption in their industries. Resources related factors are also commonly identified in the literature as contributing barriers to technology adoption. Studies on BIM adoption, for example, have identified resource issues affecting adoption including, cost (Hong et al. (2018), Ayinla et al.'s (2018), availability of capital (Khosrowshahi, F. & Arayici, Y., 2012), (Ayinla et al.'s (2018), and time pressures due to long lead time required for full-scale implementation (Ahuja, et al. (2018); Sunil et al. (2017).

For leaders, risk and uncertainty play a role in their decision making (Day, 2015). A leader's risk perception can be a crucial determinant of organisational success. For example, MacCrimmon, and Wehrung (1990), in their study of 500 executives, found that the most successful executives were the biggest risk-takers and that the most mature executives were the most risk-averse. Risk perceptions also have an impact on technology adoption. For example, Li et al. (2020) demonstrated that risk perception directly affects users' attitudes and intentions to use Alipay- a mobile payment platform. They argued that their results suggested that when users perceived that the risks of using Alipay are higher, they will hold a negative attitude about using Alipay and less likely to use Alipay. Therefore, it would be the cases that risk attitudes, uncertaininty of outcome and unternatity of return on investment will play a part in leaders risk behaviour and, therefore, impact their ability to drive digital innovation in their organisations.

6 Conclusion and Recommendations

The study aimed to explore factors that impact on digital leadership enactment in the construction industry. The industry is characteristically slow at adopting technologies. The role of business leaders is considered vital to accelerate digital transformation. While there have been many studies on digital leadership in other research fields, there is a lack of research focused on the construction industry. This study was, therefore, timely as it considered digital leadership in the construction industry. The literature has argued that unless we know what hinders digital leadership enactment, the initiatives to encourage business leaders to lead the way may be limited. Therefore this study explored barriers to digital leadership enactment. The findings suggest that the barriers to digital leadership enactment can be grouped under five themes: leadership characteristics, management and organisational issues, technological factors, resources constraints, and risk perceptions. Leaders can target these areas when designing strategies to enhance their ability to accelerate digital transformation in their organisations.

The study had two key limitations, which may impact on the interpretation of the results. First, participants were selected from a continent sample group composed of part-time postgraduate students working in the construction industry. While they had the experience to respond to the questionnaire, the sample frame may be considered as homogenous and therefore may not represent views of the construction industry population in the UK. Second, qualitative questionnaires where participants write-in responses may result in less rich data than other qualitative methods such as interviews. However, the methodology employed enabled the researchers to obtain data from a larger sample size than would have been achieved using interviews. Considering that this was an exploratory study, there are opportunities for further research on barriers to digital leadership. The results from this study can be used to design a quantitative study to capture views from a large sample size and test the significance of the influence of the different variables identified. Separate studies could also focus on each construct to enable an in-depth analysis of barriers to digital leadership enactment in the construction industry.

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Communication Challenges in Building Energy Efficiency Retrofits: Croatia Case

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Abstract
As climate change has become a growing concern, sustainable development has become increasingly important. Emissions reduction is a key step for more efficient energy use. The European Parliament implemented the Energy Efficiency Directive (2012/27/EU), which establishes a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. The building sector is the largest energy consumer in the EU; the new policies implement rules on the energy performance of buildings. In the last few years, the residential building sector in Croatia has received financial support for multi-dwelling building energy efficiency retrofits. However, some of these projects encountered difficulties due to information asymmetry between the key participants. This study addresses the problem from the perspective of the principal–agent theory, which is concerned with information asymmetry and its repercussions. A social network analysis is conducted to reflect the operation and management details of Croatian multi-dwelling buildings. The key stakeholders of energy efficiency retrofits are mapped, along with the contractual and communication ties between them. The analysis stresses the importance of the key relationship between owner representatives and property managers. Trust between them encourages communication and cooperation during project development. This study demonstrates that close cooperation between all stakeholders is essential for satisfactory project completion.

Keywords:
Communication, Croatia, Energy efficiency retrofits, Multi-dwelling buildings, Principal–agent theory, Social network analysis

1 Introduction

Energy consumption in the EU-27 reached 990 million tons of oil equivalent (Mtoe) in 2019 (European Environment Agency 2020). Large energy demand continues at a time of increasing global concern over carbon emissions and resulting global climate change (Amasyal and El-Gohary 2016). The European Parliament implemented the Energy Efficiency Directive (2012/27/EU), which established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020 (European Commission 2020). Overall EU energy consumption should be no more than 1.483 Mtoe of primary energy or 1086 Mtoe of final energy. In 2018, an amended Directive on Energy Efficiency (2018/2002) updated the policy framework to 2030 and beyond. Taking account the withdrawal of the UK, the 2030 target for EU-27 is 846 Mtoe of final energy. One of the aims of the directive is to implement national long-term renovation strategies for the building stock in each EU country. However, the newest data from the European Environment Agency (2020) warn that achieving the 2020 targets is increasingly uncertain, and that "substantial changes in the energy system will be necessary to achieve the EU's energy objectives and climate neutrality by 2050".

As the largest single energy consumer in the EU (European Commission 2020), buildings are responsible for 40% of energy consumption in the EU, and one-third of global energy consumption (Meijer *et al.* 2009). The residential sector is the second largest consumer in the EU, with 26% of final energy consumption after transport (Eurostat, 2021). The European Commission (2020) emphasises the importance of the building sector in achieving EU energy and environmental goals. The Commission has introduced a renovation wave for public and private buildings as part of the European Green Deal aiming to "take further action and create the necessary conditions to scale up renovations and reap the significant saving potential of the building sector" (European Commission 2020).

Accordingly, many European countries have enacted policy measures to achieve these goals. Energy efficiency retrofits (EERs) have become more common, but some research indicates that they are lagging behind expectations (Feser and Runst 2016). Amasyal and El-Gohary (2016) showed that a considerable number of building occupants are unsatisfied with the resulting energy efficiency, indicating that their health and/or personal productivity are negatively affected by the indoor environmental conditions after retrofit. Researchers have been investigating failures in EER projects, indicating agency problems (Liang *et al.* 2019), information asymmetry (Feser and Runst 2016; Högberg 2014) and opportunistic behaviour (Qingmiao *et al.* 2009) as the main reasons, which are all related to the principal–agent theory and communication problems between participants.

In economics, principal–agent theory describes the relationship between two or more parties; one party, designated as the principal, engages another party, designated as the agent, to perform a task on their behalf (Moe 1984; Jensen and Meckling 1976; Ross 1973). According to Moe (1984), there are information asymmetries and goal conflicts in the agency relationship. Information asymmetry considers that an agent possesses more or better information regarding the details of individual tasks assigned to him, his own actions, abilities, and preferences (see Akerlof 1970). Goal conflicts refer to conditions in which the desires and interests of the principal and the agent are in conflict with each other (Kivisto 2008). Information asymmetry and goal conflicts lead to opportunistic behaviours by participants and increasing agency costs (Kivisto 2008).

These issues come especially into focus for multi-dwelling residential buildings, which contain multiple separate housing units, each with its own owner. Retrofitting requires considerable investment, which is often not possible for homeowners, and collective decision-making among numerous stakeholders, often with diverse social and economic status (Dimitrova *et al.* 2019).

This study addresses the implementation of EER projects in Croatia, one of the EU-27 countries. The specific legislative, technical, and social aspects of the operation and management (O&M) of multi-dwelling residential buildings in Croatia are explained. A social network analysis (SNA) is conducted to map the key stakeholders. Contracts and communication ties between them are analysed, and the repercussions of principal–agent theory are discussed. The paper closes with framework focused on future research directions.

2 Energy efficiency retrofits in Croatia

Croatia entered the EU in 2013, and had to adapt its policy measures according to the EU Energy Efficiency Directive (2012/27/EU). The main actor in defining and implementing the new policy measures is the Ministry of Construction and Physical Planning (MCPP) (2020). Another important actor is the Environmental Protection and Energy Efficiency Fund (EPEEF). The EPEEF is the central point for collecting and investing budgetary resources in environmental and nature protection programmes and projects, energy efficiency, and renewable energy sources. "In the system of management and control of utilisation of EU structural instruments in Croatia, the EPEEF performs the function of Intermediate Body level 2, for the specific objectives in the field of environmental protection and sustainability of resources, climate change, energy efficiency and renewable energy sources" (Environmental Protection and Energy Efficiency Fund 2020). Since 2014, the MCPP and EPEEF have jointly managed the co-financing of EERs in Croatia, both from the state and the EU. More than 3400 multi-dwelling residential buildings in Croatia have received more than 295 million euros in incentives during the last six years (Kriz Selendic 2020)

In Croatia, the O&M of multi-dwelling residential buildings is defined by the Ownership and Other Proprietary Rights Act – OOPRA (2014). According to OOPRA, owners entrust the O&M of their building to the property manager (PM). OOPRA includes the principles of legal unity of real estate and the linking of specific parts of a building. This means that each family and business unit (dwelling) has its own owner, and all owners are together responsible for the maintenance of common areas (such as staircases, the façade, etc.). Thus, building maintenance is subject to the collective decision-making of the owners. To make this possible, owners must authorize an owner representative (OR) to represent them and protect their interests in O&M. A PM is a person or legal entity entrusted by the owners with the management of their building. The PM is obliged to protect the interests of all owners as much as possible, and must follow their instructions in O&M. His primary duty is ensuring that common areas and appliances in the building are properly maintained for normal use (Ownership and Other Proprietary Rights Act 2014). PMs are also responsible for EERs in Croatia (Nahod and Ceric 2015).

To receive state and EU incentives, more than 50% of the owners must agree to enter the process. The PM becomes a holder of their claim and represents them in front of the other actors during project implementation. For EER, designers are included in the project from the start. They are responsible for achieving the necessary energy savings after the retrofit. If the design is selected for co-financing, the PM picks the contractor responsible for executing the retrofit. For EERs in Croatia, the PM participates as a central figure in the communication and transfer of information between owners (clients), contractors, designers, and public bodies.

3 Methodology

A multitude of stakeholders and contracts signed between them provide fertile ground for agency problems. There are two key issues in agency problem, split incentive and asymmetric information (Liang *et al.* 2019). In the Croatian market, there are several principal–agent relationships to consider. To map the EER stakeholders and highlight the key relationships, a social network analysis (SNA) is conducted for EER projects in this study.

SNA is "a methodology used to identify the conditions of social structures by analysing the interactions and interrelationships of a set of actors" (Park *et al.* 2011, p. 345). It is commonly used in different fields to "understand a community by mapping the relationships that connect them as a network, and then trying to draw out key individuals, groups within the network ('components'), and/or associations between the individuals" (Home Office 2016, p. 3). SNA has been validated in other construction project research (for example, Park *et al.* 2011) and collaborative efforts research (Korba *et al.* 2006). Thus, SNA is appropriate for achieving the research objectives:

1. Map the groups in EERs.

2. Map the key individuals in EERs.

Gephi software is used in this research to conduct the SNA. Gephi is an open source software for graph and network analysis that uses a 3-D render engine to display networks in real-time and to accelerate statistical analysis (Bastian *et al.* 2009). In SNA, relationship data are visually represented and statistically evaluated following the steps shown in Figure 1. First, a visual representation is produced. All stakeholders are represented as nodes, and interactions between them are shown as ties (or edges). In this case, the only interactions are contractual and formal communication channels. The network is undirected because directional relationships (for example, messages) between actors were not considered. Network visualisation enables mapping of the stakeholder groups for EERs in Croatia.

A statistical analysis enables mapping of the key individuals. In this step, some of the network properties are calculated:

1. Degree - the number of nodes connected to a particular node (De Nooy *et al.* 2005). A node with a higher degree plays a more decisive role in information transaction (Park *et al.* 2011).

2. Centrality - a rough indicator describing the social power and influence of a node based on how well-connected the node is in the network (Park *et al.* 2011).

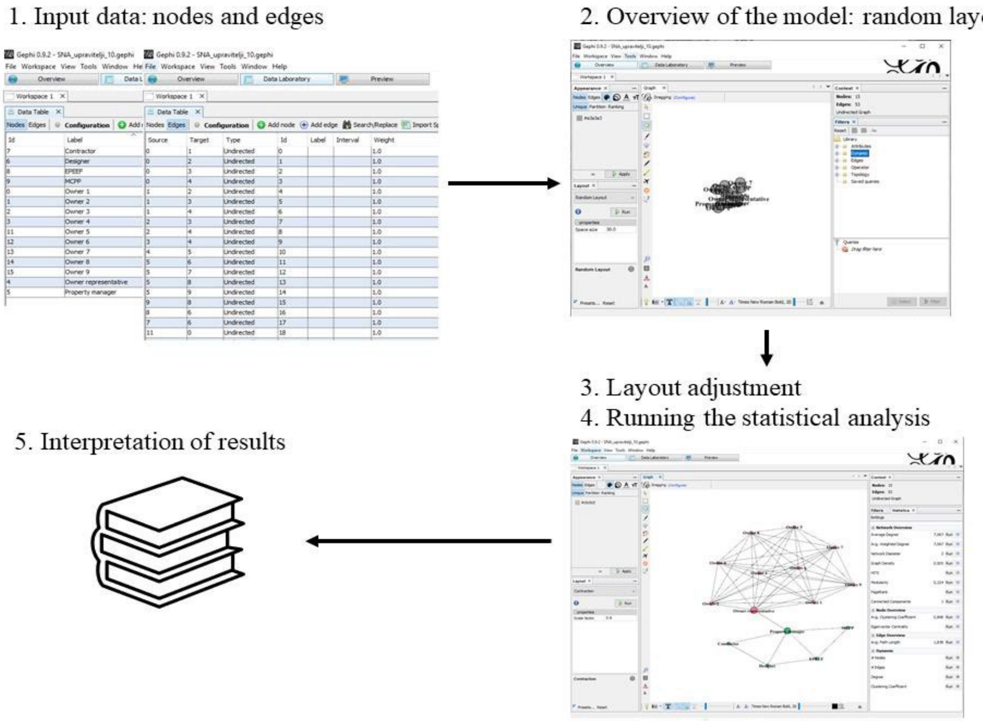

Figure 1. Conducting SNA in Gephi

The evaluated centrality types include betweenness centrality and closeness centrality (Freeman 1979). Betweenness centrality signifies the extent to which a node lies between other pairs of nodes. Closeness centrality indicates the ability to access information through other nodes.

Different scenarios were considered during the analysis to enable comparison of results regarding key individuals in a network. The scenarios included different network densities by varying the number of owners. The results are shown for two selected scenarios:

S1: EER in a multi-dwelling building with five owners;

S2: EER in a multi-dwelling building with ten owners.

4 Key findings

Key findings of the presented SNA were organized to explore defined research objectives. The analysis indicated two different "clusters", or groups of stakeholders in EERs in Croatia, and enabled the mapping of key relationships between stakeholders.

4.1 Groups of stakeholders

Visual representation of social contacts between stakeholders during EERs in Croatia is depicted in Figure 2 and Figure 3. These figures represent different scenarios for multi-dwelling buildings, with five and ten owners, respectively. Both social networks are divided into two clusters, *red* and *green*. A *red cluster* represents a group of stakeholders living in a building experiencing a retrofit. Owners and their representative are clients, but the communication between the nodes is relatively enclosed, enabling external information exchange only through their representative. Similarly, the *green cluster* is organized around a property manager. Public institutions, designers, and contractors exchange information with the property manager, not directly with clients. The difference is that communication between the nodes in a *green cluster* is more restricted than in a *red cluster*; thus, the nodes are not entirely interconnected.

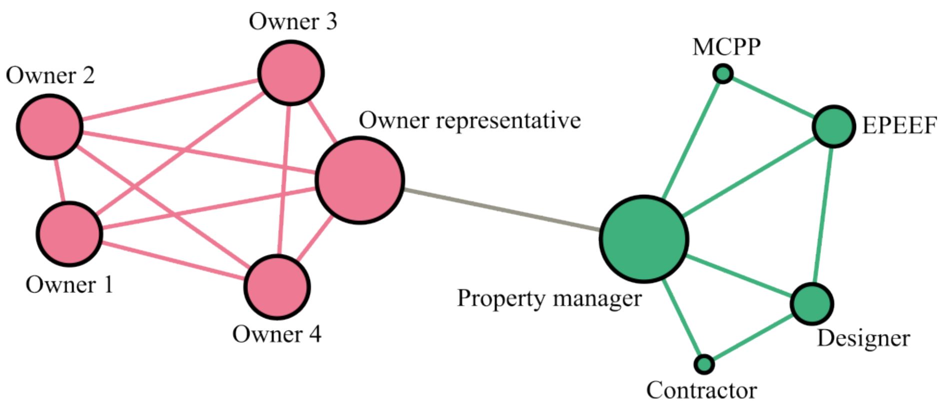

Figure 2. SNA for S1 – visual representation

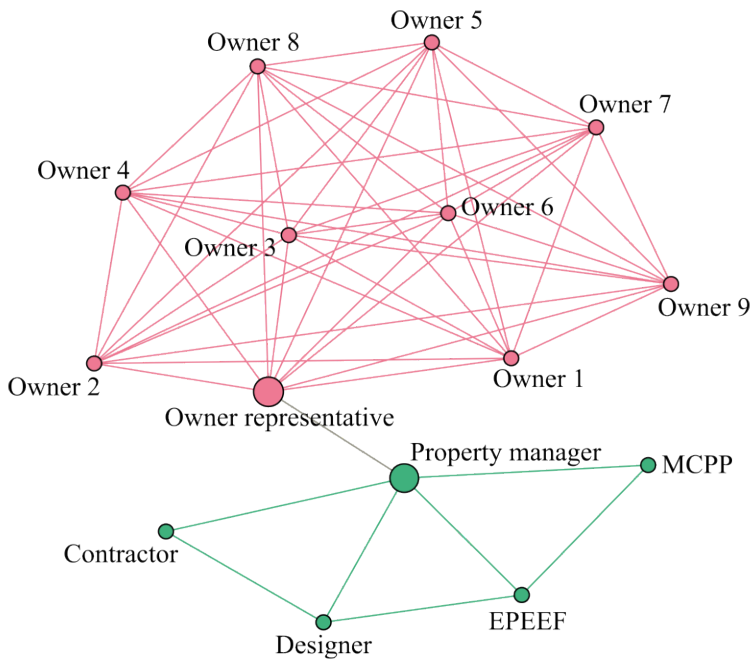

Figure 3. SNA for S2 – visual representation

4.2 A key relationship

After identification of two clusters in an EER network, it is obvious that the relationship between the OR and PM is the only tie enabling information flow between different stakeholder groups. Further statistical analysis also emphasises the importance of two key stakeholders in EERs in Croatia.

Table 1 presents a comparison of two scenarios, with five (S1) and ten (S2) building owners. Centrality measures depict the actual social power and influence of a node. According to betweenness centrality, the OR and PM are by far the most important participants in a network. Their importance increases with an increase in the number of owners; the social power and influence of owners remains 0.0 in both scenarios. The social power and influence of other participants is rather similar to that of the owners, and is not dependent on the number of owners. The OR and PM control the majority of information flowing in a network during an EER. Nevertheless, their roles in a network are fairly different. According to Home Office (2016), if a node has a high betweenness and a low degree, it can be considered as a gatekeeper. If a node has a high betweenness and a high degree, it indicates a central figure in the network. Thus, a PM for a building with more than five owners is a typical gatekeeper of information. He may play an important role in activity, but not much information is held by him. Removing this node from the network may cause fragmentation (Home Office 2016). According to Haas (2015), gatekeepers play an important role in decision processes by regulating information flows. They can also withhold access to information from participants in another group, and can be an obstacle to information exchange or access to decision-makers within the group (Haas 2015). They can have a filtering role in the network.

An OR is highly visible and has a central role in a network (Home Office 2016). An OR can be considered as a boundary spanner, an interpreter of environmental conditions, and a provider of information to decision-makers (Haas 2015). ORs bring together knowledge from different groups as they are responsible for contacting persons outside of their own group (Haas 2015). According to Home Office (2016), they represent key participants that may be focused on fragmenting networks and gathering information. However, much information flows between the owners, as indicated by high closeness centrality. Owners may be involved in many activities in a network, but do not play a unique role (Home Office 2016). This is especially true with a multitude of owners when they are connected to each other and have a high degree, but their centrality remains 0.0. Other participants in a network such as a designer, a contractor, and public bodies also provide information, but do not have a key role in communication.

Table 1. SNA – comparison of S1 and S2

Node	Degree (S1)	Betweenness centrality (S1)	Closeness centrality (S1)	Degree (S2)	Betweenness centrality (S2)	Closeness centrality (S2)
Owners	4.0	0.0	0.5	**9.0**	0.0	0.61
OR	**5.0**	**20.0**	**0.69**	**10.0**	**45.0**	**0.78**
PM	**5.0**	**22.0**	**0.69**	5.0	**42.0**	0.61
Designer	3.0	0.5	0.47	3.0	0.5	0.41
Contractor	2.0	0.0	0.45	2.0	0.0	0.4
EPEEF	3.0	0.5	0.47	3.0	0.5	0.41
MCPP	2.0	0.0	0.45	2.0	0.0	0.4

Relevant findings of previous literature are somewhat different than the results of this study because they depend on country's legislation and a specific environment in question. For example, Xu *et al.* (2021) conducted a SNA to investigate the stakeholders' power over the impact issues of building energy efficiency in China. Their results indicate that the most influential stakeholders in China are designers, manufacturers, commissioning agents and researchers. Nevertheless, the measures they use are similar as in this study (measures of centrality). The unique role of PM is specific for Croatian context. Nahod and Ceric (2015) mentioned the importance of PMs in EERs in Croatia, but this study has further explained their role in information exchange between owners and other participants in a network.

5 Framework for principal–agent model for EERs in Croatia

According to previous literature (Xu *et al.* 2021), insufficient knowledge and experience, lack of information integrity and unclear responsibility can be a serious threat for enhancing energy efficiency. Other researchers have also indicated that agency problems (Liang *et al.* 2019), information asymmetry (Feser and Runst 2016; Högberg 2014) and opportunistic behaviour (Qingmiao *et al.* 2009) are the main reasons for failures in EER projects, which are all related to the principal–agent theory and communication problems between participants.

Feser and Runst (2016) investigated the information asymmetry between owners and public energy efficiency consultants as change agents in Germany. In Germany and in other countries, such as Sweden, Finland, Belgium, Denmark, USA, and UK, energy efficiency consultants have been promoted to overcome information asymmetry problems and increase transparency, information flows and ex-post quality controls. They also mention the information asymmetry between owners and construction companies performing the EERs. In China, researchers (Qingmiao *et al.* 2009) investigated the principal-agent problem between the government and the owners. Nevertheless, this study has shown that EPEEF (as the consultant body) and MCPP (as the government body) do not have a central role in the Croatian context and cannot influence the information flow as much as PM and OR.

SNA results for EER projects in Croatia emphasise the key relationship between the OR and the PM. They are recognised as boundary spanners and gatekeepers of information in the network. Regarding communications, the responsibility of the OR is to overcome boundaries and facilitate communication and information exchange between the owners and the PM. The PM controls what information passes from one group (owners) to another (other stakeholders). The role of the PM can be considered negatively with hoarding of information, or positively with sharing of useful information and filtering of irrelevant information (Long *et al.* 2013). Gatekeepers have attributes and make decisions that may not be visible to owners (Shumsky and Pinker 2003), leading to a principal–agent model with information asymmetry between the PM and owners. A key principal–agent issue arises with self-interest, or because stakeholders are not willing to share all information all of the time.

There are three types of information asymmetries that apply in this case: hidden characteristics, hidden information, and hidden intention. These information asymmetries generate the risk of adverse selection, moral hazard, and hold-up, respectively. Adverse selection occurs when owners do not know the exact qualifications of the PM before the contract is signed. Moral hazard occurs when owners cannot be sure that the PM will fully act on their behalf after the contract is signed. Hold-up occurs when owners have invested resources in the belief that the PM will behave appropriately, but instead he acts opportunistically after the contract is signed (Jäger 2008; Schieg 2008).

In Croatia, the principals hire a representative, the OR, to protect their interests. A property management firm can employ a representative to manage a specific building case. A detailed principal–agent model for key EER stakeholders is shown in Figure 4. As agents, the owner and PM representatives are in a non-contractual relationship; the other stakeholders are in contractual relationships.

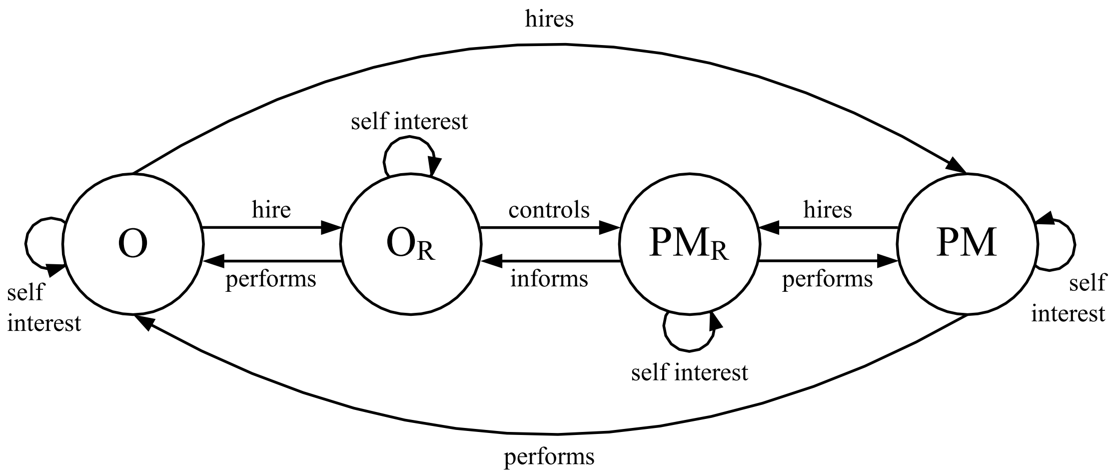

Figure 4. Principal–agent model for key EER stakeholders (O – owners; O_R – owner representative; PM – property manager; PM_R – property manager representative)

A proposed framework is a useful understanding of how all the relationships are intertwined in EER projects. According to Jäger (2008) and Schieg (2008), owners can minimize risks by screening and monitoring the intentions of the PM. The purpose of screening is to gather information for the owners in an effort to learn more about the qualifications of the PM, including references, certificates, work probes, and credit worthiness, reducing the risk of adverse selection. Similarly, the purpose of monitoring the PM is to ensure that they are behaving in the best interest of the owners, to reduce moral hazard and hold-up risks. Ceric (2016) emphasised the importance of trust between the two representatives, and the use of information technology and communication protocols to enable successful communication and coordination. In the future, modern technologies such as blockchain can also minimize information asymmetries and risks in EERs. Research on blockchain technology and its applications in projects related to energy efficiency retrofits has begun (Aoun 2020). Blockchain technology ensures that all project participants have access to all information exchanged between them over the project duration. It can significantly reduce information asymmetry and produce more trustful relationships between project stakeholders (Ceric 2019). The proposed framework is a useful pointer for future research in applying principal-agent theory in EER projects.

6 Conclusions

This study provides insight into the social network of energy efficiency retrofits, which have become more common in Croatia in recent years. Increasing global concern over carbon emissions and climate change has resulted in implementation of a wide variety of policy measures directed to increase the energy efficiency of buildings. EERs in Croatia have been especially oriented to multi-dwelling residential buildings, which have received incentives from the state and the EU. Nevertheless, the EERs of these buildings have encountered some problems, with numerous privately-owned dwellings and shared ownership of the common areas. Scientific research conducted in other countries indicates that agency problems, information asymmetry, and opportunistic behaviour are the main causes. Thus, there was a need to investigate social and communication networks, and the repercussions of principal–agent theory on EERs in Croatia.

The social network analysis results emphasise the importance and centrality of two key participants in an EER network in Croatia – the owner representative and the property manager. They are recognised as the boundary spanners and gatekeepers of information in this network. As such, they control the flow of information between the owners and other stakeholders such as contractors, designers, and public bodies. They both have great social power and great influence on the success of project communication.

The directed interactions between stakeholders were not tracked during this study; the results are limited in this way. This study was intended to provide insight into undirected contractual relationships and formal communication channels. With broader input data, social network analysis can provide even more detailed information regarding social interactions between stakeholders. Future researchers are encouraged to consider this challenge. The results of this study provide a starting point for much broader research of information asymmetry and strategies for its minimization in future EER projects. Some possible directions include application of new information technologies (such as blockchain), developing communication protocols, and building trust between stakeholders in EERs.

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Track 5

Sustainability and the Environment

A Review on Embodied Carbon Reduction Strategies of Iron and Steel Building Products

Carbon Reduction during Building Construction Projects – Trend Mapping from Construction Journals

Integrating Users Satisfaction to Support Decisions in Sustainable Developments

Towards Automation of Sustainable Green Building Materials in India

Economics and Management of Smart BE

Developing an Early Prediction Model of Bankruptcy in the UAE Construction Industry

Accelerating Innovation Process

An Investigation of the Influence of Public Clients on Contractors' Behaviour towards the Modern Methods of Construction

A Review on Embodied Carbon Reduction Strategies of Iron and Steel Building Products

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Abstract
Whilst the operational carbon emission of building continues to attract significant attention, the embodied carbon emission of building materials receives increasing attention in both industrial and academic fields. Iron and steel are very popular building materials in modern construction and they are among the most carbon-intensive building materials. In recent years, numbers of studies have been conducted to disclose the embodied carbon emission of iron and steel building products and explore the possible carbon reduction strategies. This study aims for discovering the status quo and features of the available carbon reduction strategies of iron and steel building products through an review on existing literatures. Numbers of reduction strategies have been identified through a broad review of research articles and subsequently been systematically analyzed. Results of this study reveal that alternative fuel & renewable energy, alternative ironmaking processes, alternative reducing agents, carbon capture and storage, waste gas recovering, are key measures to achieve low-embodied-carbon iron and steel building products. In many cases, the carbon reduction strategies work cooperatively to achieve maximum performance. Alarmingly, the impacts of policy drivers, and management measures such as a thorough life cycle analysis of manufacturing process and use of local raw materials have been overlooked in most researches. The challenges and barriers of implementing the reduction strategies have also been discussed in this research.

Keywords
Carbon emission reduction strategies, embodied carbon of building, iron and steel building products

1 Introduction

The building sector puts the most environmental pressure on the earth. It is among the sectors that consume most energy and generate most carbon emissions (Praseeda *et al.*, 2016). In the European Union (EU), buildings are responsible for 42% of the energy consumption and 35% of greenhouse gases (GHGs) predominantly carbon dioxide (EC, 2011). Early researches in the field of building carbon footprint have put their emphasis on the operational emission reduction, as the operational emission accounts for the largest part throughout building lifecycle. With the growing application of energy efficiency measures, the proportion of operational energy has been considerable reduced in recent years. As a result, the research focus has been gradually shifted to the reduction strategies of embodied carbon of building. The biggest proportion of building embodied carbon is the building material embodied carbon, i.e., the carbon emissions related to production of building materials (also called "cradle-to-site" carbon emission). In some European countries, the manufacturing of building material generated around 10% of the nations' total carbon emissions (Gielen, 1997). Among the numerous of building materials, iron and steel products are ones of the most commonly used and ones with the largest carbon intensity. Researches have proved that, structural materials i.e., concrete and steel, have the largest carbon emission shares in modern construction (Oma, 2018; Wen *et al.*, 2015; Kua and Wang, 2012).

The demand of global crude steel is predicted to be increased by 122% by 2050 (IEA, 2009). Being one of the industry sectors that have the most energy and carbon saving potential, iron and steel industry has the obligation on carbon reduction. Therefore, in recent decades, increasing number of researches have been conducted aiming for mitigating the embodied carbon of iron and steel products. In spite of the increasing researches on this topic, very limited studies have been conducted to systematically review the available results of them. Quader *et al.* (2015) comprehensively reviewed the breakthrough technologies for improving the energy efficiency and carbon emission of iron and steel manufacturing. Ren *et al.* (2021) reviewed numbers of carbon reduction technologies and estimated their reduction potential through integrating the results of the reviewed studies. Quader *et al.* (2015), Quader *et al.* (2016) and Ren *et al.* (2021) have also provided cost analysis of the carbon reduction strategies. These review articles focused on the emerging technologies applied during the manufacturing of iron and steel products. Unfortunately, very few of them mentions the importance of management and political measures. Besides, these review articles did not provide a holistic review of the carbon reduction strategies throughout a cradle-to-site boundary.

Therefore, this paper holistically reviews the relevant existing researches with an aim to identify the carbon reduction strategies of the production routes of iron and steel building products within the cradle-to-site boundary. Through a systematic analysis of the reviewed research results, this paper summarizes the status quo and features of the existing carbon reduction strategies applied in the manufacturing of iron and steel building products. The limitations and barriers of implementing the reduction strategies have also been discussed. The findings of this study will form part of the contribution to the body of knowledge and also help the industrial practitioners in the relative fields to improve their environmental strategies.

2 Methodology

This study begins with a search of peer-reviewed journal articles in the relevant field. The search results only consider the articles published in the latest 10 years because it is a rapidly developing research topic. This reviewing study focus on the low-carbon (energy efficient) strategies applied in production of the iron and steel building products within the cradle-to-site boundary. Keywords are proposed to be searched across a commonly recognized literature database i.e., Science Direct. The following keywords and combination of keywords were searched in the literature database:

- Iron and steel building products
- Embodied carbon/CO_2/GHG/energy
- Carbon/CO_2/GHG mitigation/reduction
- Energy efficiency
- Ironmaking and steelmaking

The titles of more than 400 peer-reviewed journal article were identified falling within the keywords area. After an initial scrutiny of abstracts, 46 representative articles were selected for this reviewing study as they provided detailed analysis of carbon reduction (energy efficiency) strategies.

3 Findings and Discussions

After a detailed scrutiny of the selected research articles, 10 (groups of) carbon reduction strategies within the cradle-to-site boundary of iron and steel building products were identified (Table 1).

Table 1. Carbon Reduction Strategies (CRS) Identified in the Reviewed Articles

Carbon Reduction Strategy (CRS)	
CRS1	Improving equipment efficiency/productivity for raw material preparation
CRS2	Dry quenching of coke
CRS3	Alternative ironmaking technologies
CRS4	Alternative reducing agents
CRS5	Scrap recycling
CRS6	Waste gases recovery
CRS7	Alternative fuel & renewable energy
CRS8	Carbon capture and storage
CRS9	Management measures
CRS10	Policy drivers

3.1 Carbon Reduction Strategies

3.1.1 Improving Equipment Efficiency/Productivity for Raw Material Preparation

Ferreira and Leite (2015) carried out a lifecycle assessment of iron ore mining. Their study found the consumption of electricity leading the carbon emission of entire mining process. Thus, they have identified the electricity from renewable sources e.g., hydroelectric plants as an efficient carbon reduction strategy. Gan and Griffin (2018) conducted research on carbon assessment for up-stream processes such as iron ore mining, ore processing, sintering, pelletizing, and associated transportation. In their research two carbon reduction possibility were identified: i) open pit mining rather than underground mining and, ii) increasing the proportion of pelletized iron ore over sintered iron ore.

3.1.2 Dry Quenching of Coke

Coke is an essential feedstock of blast furnace ironmaking. The extremely hot coke (approx. 1,200°C) made in coke oven must be cooled down to proper temperature in order to be used for the following ironmaking process. The traditional way of cooling is realized by spraying cooling water. This method leads to high carbon emissions and heat loss. The coke dry quenching process was consequently proposed. In this method, the hot coke is cooled by blown in circulated gas in a coke cooling tower. The coke is cooled down meanwhile the gas is heated to a high temperature and readily to be reused in waste heat boiler. The coke dry quenching has numbers of advantages including less carbon emission, waste heat recovery, less moisture content of coke, less cost and etc.

3.1.3 Alternative Ironmaking Technologies

The commonly alternative ironmaking technologies include direct reduction of iron ore, and electrolysis of iron ore. The principal reaction of direct reduction of iron ore is to reduce iron ore to iron into the solid-state i.e., in the form of pellets. Coal, CH_4 and H_2 can be used as reduced agents. Instead of blast furnace, the direct reduction process takes place in shaft furnace. A number of chemical reactions happen in the shaft furnace. The final direct reduced iron (DRI) can be used in subsequent handling i.e., electrical arc furnace (EAF) steelmaking. The most commonly mentioned DRI making is that with hydrogen (H_2), also called hydrogen direct reduction (H-DR).

Electrolysis has been used for decades to extract metal ion from ore in many metallurgical industries such as aluminium and copper. The principle of direct electrolysis of iron ore is similar as other metal electrolysis. It takes place in the electrolyte with required temperature and with cathode and anode presented. The ferric ion gathered in the cathode and the oxygen is collected in the anode side. Thus, it is deemed as zero-carbon emission technology in many researches (Quader *et al.*, 2016).

3.1.4 Alternative Reducing Agents

Many materials can be used as substitution of coal and coke as reducing agent in ironmaking such as oil, CH_4, H_2, plastics, pulverized coal, coke oven gas, biomass and etc. Among them, the coke oven gases (containing rich CH_4 and H_2) and biomass are recognized as top options for low-carbon ironmaking. As by-products of coke-making, the coke oven gases, if reused as reducing agent, results in zero environmental burden in the ironmaking process. H_2 based ironmaking, i.e. DRI making, has been regarded as one of the most effective carbon emission reduction strategies (Ren *et al*., 2021). In the other hand, biomass is also an ideal substitution of coal and coke as reducing agent both in blast furnace and DRI route ironmaking. Study has proved that employing biomass reducing agent decrease the overall cost and reduce carbon emissions by 20 million tons (Fu *et al*., 2012).

3.1.5 Scrap Recycling

The EAF steelmaking route can substantially reduce the carbon footprint of steel product as it eliminates the most carbon intensive processes i.e., coke-making, sintering, ironmaking, and BOF steelmaking. Research has proved that if the electricity used for EAF is generated by clean energy such as hydropower, wind power and nuclear power, ultra-low carbon production can be achieved (Quader *et al.*, 2015). EAF route steelmaking consumed half of the energy of BF-BOF route (Hernandez *et al.*, 2018). That means the growth of shares of EAF can be an effective way of carbon reduction. Unfortunately, in the developing countries such as China, the relatively high price of electricity and cost of steel scrap hinder the widespread of EAF route steelmaking (Ren *et al*., 2021).

3.1.6 Waste Gas Recovering

The exhaust gases of coke oven, blast furnace and basic oxygen furnace contain CO_2, CO, H_2, N_2, CH_4 and etc., among which the CO, H_2, CH_4 can be utilized as fuel in the iron and steel making plants. Besides, the hot exhaust gases of coke oven contain massive heat which can be used for pre-heating processes in coke making plant; the waste gases of blast furnace and basic oxygen furnace can be used as heating gases in iron and steel plants, as well as reheating gases in rolling mill. Moreover, owning to its chemical properties, the blast furnace top gases, containing rich H_2 and CH_4, which can be use as reducing agent in ironmaking. In additional to these, the exhaust gases are proposed to be used beyond iron and steel production, such as to provide heat and energy in power plants and as feedstock for methanol production plant (Lundgren *et al.*, 2013).

3.1.7 Alternative Fuels & Renewable Energy

Biofuels such as charcoal made from biomass can be used in sintering and ironmaking process (Wai *et al.*, 2017). Previous studies proved that the net carbon emission released from blast furnace can be reduced by 90% (Nogami *et al.*, 2004) and 96% (Ng *et al.*, 2011) if biomass charcoal is used as substitute of fossil fuels. Besides, biomass fuels can also be adopted as alternative fuel in the EAF. Oliveira *et al.* (2015) demonstrated a biomass integrated gasification combined cycle for generation of electricity and thermal energy for EAF steelmaking. The results shown that adopting biomass fuel yields much lower net CO_2 emission than that of fossil fuel. However, this novel approach is in theoretical stage and further study is required.

3.1.8 Carbon Capture and Storage

Carbon capture and storage is the umbrella term for the technologies of capturing carbon emissions from major emission sources, then transporting, sequestrating or storing for further industrial usage. The commonly available carbon capture technologies include pressure swing adsorption, membrane adsorption, chemical absorption, physisorption and etc. The captured CO_2 is usually liquefied for the ease of transported. Captured carbon can be used as feedstock for methanol production, fuel production, syngas (CO and H_2) production, and gas and bio fertilizer. The most common way of carbon sequestration is geological sequestration including land sequestration, seabed saline aquifer sequestration, depleted oil or gas reservoir sequestration and etc. (Ras *et al.*, 2019).

3.1.9 Management Measures

During the scrutiny of the abstracts of articles in the initial screening, it was found that very few researches explored the carbon reduction potential of carbon management measures. Ren *et al.* (2021) mentioned about several management measures to improve the energy consumption and carbon emissions in the iron and steel industry in China. They included mitigating the iron and steel products consumption i.e., increasing the service life of iron and steel products, and production management technologies i.e., information technology empowered management. Other management measures include energy monitoring and management, lifecycle energy/carbon assessment, use of local raw materials and etc. However, these measures were barely mentioned in the examined articles let alone an analysis of their carbon reduction potential.

3.1.10 Policy Drivers

The situation of policy drivers is similar to that of management measures. Few researches mentioned about or recommended policies that improve energy efficiency and carbon mitigation. In developed countries, the development towards low-carbon iron and steel industry has gained considerable supports from governments or NGOs. There are spotted initiatives emerging in China in recent years, mainly initiated by private iron and steel manufactures. Yu *et al.* (2015) studied the impact of economics and policy intervention in Chinese iron and steel industry with regards to carbon emission. The results shown that investment in technologies would significantly reduce carbon emission, but the investment expansion had a negative impact on carbon mitigation (Yu *et al.*, 2015).

3.2 Synergy of Carbon Reduction Measures

Table 2 summarizes the reviewed literatures on the embodied carbon reduction strategies of iron and steel building products. It can be observed that about half of previous researches analysed the feasible or performance of multiple carbon reduction strategies as an integrated system. It further proves that carbon reduction strategies work cooperatively to achieve maximum performance as deemed in many researches (Quader *et al.*, 2015; Zeng *et al.*, 2009). For example, the H-DR ironmaking followed by EAF steelmaking coupled with furnace gas recovery and cabon capture and storage technology could achieve completely fossil fuel free iron and steel production and ultimate carbon reduction (Otto *et al.*, 2017).

Table 2. Carbon Reduction Strategies (CRS) Identified in the Reviewed Articles

Literature	**Country/ Region**	**Carbon Reduction Strategies (CRS)**									
		CRS1	**CRS2**	**CRS3**	**CRS4**	**CRS5**	**CRS6**	**CRS7**	**CRS8**	**CRS9**	**CRS10**
Awuah-Offei and Adekpedjou, 2011	NA									√	
Kirschen et al., 2011	Germany			√							
Fu et al., 2012	Taiwan				√						
Ghanbari et al., 2012	Finland				√			√			
Ansari and Seifi, 2012	Iran										√
Giannetti et al., 2013	Brazil									√	
de Castro et al., 2013	Brazil				√						
Ho et al., 2013	Australia								√		
Hui et al., 2013	China						√				
Johansson, 2013	Sweden							√			
Germeshuizen and Blom, 2013	South Africa			√				√			
Arens and Worrell, 2014	German		√		√		√				
Arasto et al., 2014	Finland			√					√		
Han et al., 2014	Korea						√		√		
Tsupari et al., 2015	Finland			√					√		
Li and Zhu, 2015	China	√	√		√	√	√			√	
Yu et al., 2015	China										√
Quader *et al.*, 2015	EU						√		√		
Ghanbari et al., 2015	Finland				√		√	√	√		
Ferreira and Leite, 2015	Brazil							√			
Oliveira et al., 2015	Brazil							√			
Weigel et al., 2016	Germany			√					√		
Quader et al., 2016	EU			√	√		√		√		
Pal et al., 2016	Indian			√					√		
Guo et al., 2016	China				√						
Pohlmann et al., 2016	Brazil							√			
Cheng et al., 2016	China							√			
Yilmaz et al., 2017	Germany			√							
Otto et al., 2017	Germany			√		√		√	√		
Zhang et al., 2017	China						√				
Wei et al., 2017	NA							√			
Vogl et al., 2018	Sweden			√				√			
Gan and Griffin, 2018	China	√									
Shen et al., 2018	China									√	
An et al., 2018	China										√
Mandova et al., 2018	EU							√			
Suopajärvi et al., 2018	Sweden & Finland				√			√			
Ras et al., 2019	NA								√		
Long et al., 2020	China				√	√		√			
Lin and Wu, 2020	China										√
Ren et al., 2021	China			√			√		√	√	
Müller et al., 2021	German			√		√		√			
Pimm et al., 2021	UK			√				√			
Yu et al., 2021	China				√						
Liu et al., 2021	China			√	√			√			
Purhamadani et al., 2021	Iran	√									
	Total:	**3**	**2**	**14**	**12**	**4**	**9**	**17**	**12**	**5**	**4**
	% (out of 46):	**7%**	**4%**	**30%**	**26%**	**9%**	**20%**	**37%**	**26%**	**11%**	**9%**

3.3 Lack of Management Measures and Policy Drivers

It is observed that the CRS7 alternative fuel & renewable energy (37% of researches mentioned), CRS3 alternative ironmaking processes (30% of researches mentioned), CRS4 alternative reducing agents (26% of researches mentioned), CRS8 carbon capture and storage (26% of researches mentioned), and CRS6 waste gases recovery (20% of researches mentioned) rank top 5 most mentioned carbon reduction strategies in the reviewed 46 researches. Which is in line with the facts that the fossil fuel basis blast furnace ironmaking generates the largest proportion of the cradle-to-site carbon emissions of iron and steel products.

On the other hand, management measures and policy drivers have been severely overlooked. Adopting local raw materials should be regarded as an important carbon management measure. Take China as an example, more than half of the iron ore were imported from overseas including Australia (22.5%), Brazil (7.7%), South Africa (1.5%), India (0.8%) (GACPRC, 2019). If the same transportation mode i.e. shipping applied, the increase of import proportions from Asia or near Asia areas can substantially reduce the transportation associated carbon emissions. However, none of the reviewed study mentioned such management improvements. Besides, a thorough a lifecycle energy/carbon assessment of manufacturing process is an also effective way to perform better energy/carbon management, which is unfotunately barely mentioned in the reviewed articles.

3.4 Challenges and Technology Barriers of Implementing the Carbon Reduction Strategies

3.4.1 Direct Reduction of Iron Ore with Hydrogen

The main challenge of direct reduction of iron ore with H_2 is the availability and cost (Chevrier, 2020). The costly distribution infrastructure, purify system and associate safety issues are major challenges of its large-scale application. It’s worth noting that majority of the global H_2 are produced from fossil fuels (mostly natural gas) by steam methane reformer using natural gas as the feed-stock. The final outputs contain H_2 and CO which can be easily converted to CO_2. Therefore, the popular mode of H_2 production today is not a low-carbon process. In other words, although the DRI route is a low-carbon process, the H_2 which used as feed stock is embodied with considerable carbon emission. Thus, DRI can be regarded as the most efficient way to reduce the embodied carbon of ironmaking only if paired with sustainably produced H_2.

3.4.2 Electrolysis of Iron Ore

Compared to the blast furnace and DRI route, direct electrolysis of iron ore generates nearly zero carbon emissions and costs less. But this is a relatively new ironmaking method and has not been applied in commercial scale. This is because of its low productivity due to reaction rate i.e., 5 kg iron per day (Quader *et al.*, 2016). Recent research in EU has been experimenting rising the reaction temperature in order to boost the reaction speed (Müller *et al.*, 2021). This method was predicted could be applied in industry in 2030s (Quader *et al.*, 2016).

3.4.3 Waste Gas Recovering

The exhausted gases of an integrated steel mill are usually a mixture of various gases with massive residual heat. The waste gas recovering has great potential in terms of carbon emission reduction. However, the efficiency of gas separation/utilization/scheduling systems in steel mill is the biggest challenge posed in front of the industry and researchers.

3.4.4 Carbon Capture and Storage

As the fossil fuels are irreplaceable in the near future in the iron and steel industry, it is foreseeable that the carbon capture and storage would play an important role in the embodied carbon reduction strategy. However, there are still numbers of difficulties to be solved before this method being maturely adopted. The efficiency of carbon capture depends on the concentration and purity of CO_2. The technical issues of concentrating the CO_2 and eliminating the impurities are yet to be improved. Besides, transportation and storage of CO_2 requires infrastructures such as land, infrastructures, storage technologies, logistical facilities, which give rise to challenges including high capital cost and long project development times, investment risk, lack of financial incentives, concerns of operational safety and etc. (IPCC, 2014a, b).

4 Conclusions and Further Research

Concerning the intensive embodied carbon emissions of iron and steel building products, abundant researches have been carried out to propose and evaluate the carbon reduction strategies. This reviewing study has identified the available embodied carbon reduction strategies of iron and steel building products in recently published literatures. 46 relevent peer-reviewed articles have been reviewed and 10 carbon reduction strategies have been identified. It is observed that alternative fuel & renewable energy, alternative ironmaking processes, alternative reducing agents, carbon capture and storage, waste gas recovering, are the most frequentely studied technology improvements to achieve low-carbon iron and steel building products. The carbon reduction strategies ususally work cooperatively to achieve maximum performance. Although been most analysied in the existing literatures, the abovementioned technology measures have their limitations and barriers during implementation. One important finding of this study is that the relevent policy drivers and management measures have been largely igored in existing literaures. The findings of this study are expected to contribute to the body of knowledge and also help the industrial practitioners to improve their environmental strategies.

Due to the word limit of the conference paper, only 46 peer-reviewed articles have been reviewed in this study. Therefore, more articles should be covered in the future reviewing study. Besides, quantitative evaluation of carbon reduction potential should be further reviewed in order to disclose the effectiveness of the emerging carbon reduction strategies of iron and steel building products.

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Carbon Reduction during Building Construction Projects – Trend Mapping from Construction Journals

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Abstract
In recent times, there has been an increasing attention on embodied carbon reduction of building construction projects. However, most of this attention have been concentrated on carbon emission related to materials used for building construction while construction activity related carbon emission seems to have been largely ignored. Hence, this paper examines this claim by analysing literatures in construction management journals published between year 2000 and 2021. The authors performed the analysis by examining the annual publication of research related to carbon reduction during the construction phase of building projects, geographical spread and/or institution of authors who have contributed to these studies, and key research themes covered. The systemic review of literature conducted shows that there seems to be very little research published relating to carbon reduction during building construction projects. Also, the findings suggest that carbon reduction during building construction project related research have only just been in mainstream publication in the last five years with this research largely domiciled in China, US, Australia, and Hong Kong. Furthermore, it was discovered that most of the existing research related to the focus of this paper was done in the context of life cycle analysis or assessment. Research gaps were highlighted, and future research path is proposed. It is likely that the findings of this study may arouse researchers with interest in construction carbon reduction and industry stakeholders alike.

Keywords
Carbon Reduction, Construction Carbon, Construction Journals, Building Construction Projects

1 Introduction

Embodied carbon reduction in building construction projects has been of increasing concern lately amongst researchers and practitioners. This is logical since Huang *et al.* (2018) noted that in 2009 alone, embodied carbon emission from the construction industry contributes about 23% of the world's total carbon emission. Also, embodied carbon emission has been predicted to continuously grow as the world adds more floor area and it is suggested that by 2050, half of the entire carbon footprint of new construction will be embodied carbon (UN Environment and International Energy Agency 2017). Hence, this desire to minimise embodied carbon can be attributed to the drive by relevant stakeholders in decarbonising the construction sector (Arogundade 2021) while pushing towards the actualisation of net zero carbon buildings by 2050 as advanced by the World Green Building Council (World GBC 2016).

However, this push in reducing embodied carbon seems to have been lopsided as most of this attention have been concentrated on carbon emission related to materials used in building construction while construction activity related carbon emission appears to have been largely ignored. This is probably due to the fact that material selection is done during the design stage of a building construction project thereby favouring the selection of a low-carbon material which is believed to assist in minimising embodied carbon emission. Another factor includes the perception that construction materials has the highest embodied carbon emission when the life cycle assessment of a building is put into consideration (Resch *et al.* 2020 and UKGBC 2015) and the notion that construction stage carbon emission is very low (Kong *et al.* 2020). Victoria and Perera (2018) however noted that while the quantities of material and their related embodied carbon data forms the foundational basis of conducting embodied carbon assessment, other factors such as the assumption of the individual carrying out the assessment; scope of analysis; data sources; system boundary; and the estimation method used - affects the embodied carbon measurement. Therefore, the believe that construction related carbon emission is quite low is debatable.

For instance, in the study conducted by Hong *et al.* (2015), the authors extended the system boundary of the embodied carbon calculation during the construction phase of a building project in China to include emission from human activities involved in the building construction and found out that an additional 385 tCO2e was emitted during the building construction. This human related emission would not have been captured if the authors did not extend the boundary of their embodied carbon measurement.

Based on this backdrop, it is apparent that some gap still exists in the research domain related to the actual contribution of carbon emission associated with construction activities during building construction projects as well as in understanding efforts in reducing same. Consequently, this study seeks to plug this knowledge gap by answering these three research questions:

a) What has been the annual publication of studies related to carbon reduction during the construction phase of building projects in the last two decades (2000 – 2021)?

b) What is the geographical spread and/or institution of authors who have contributed to studies related to carbon reduction during the construction phase of building projects within this period?

c) What key themes or areas of research have been covered or is emerging?

To tackle the research questions, the authors analysed literatures in construction management journals and conference proceedings published between year 2000 and 2021 (as of 8 March 2021) by using a systemic analysis approach. This method was adopted based on its wide usage by researchers when conducting research of this nature especially in gaining an understanding of development in a particular subject domain (Darko and Chan 2016). It is therefore hoped that the findings of this study will further contribute to the body of knowledge in the area of construction carbon emission and its reduction while equally arousing researchers with interest in construction carbon reduction and industry stakeholders alike.

2 Embodied Carbon Emissions during a Building Construction Project

Embodied carbon emissions during a building construction project are emissions associated with the construction, renovation/refurbishment and eventual end of life stage of the building (Huang *et al.* 2018). These emissions have been succinctly categorised by adopting the European standard EN 15978 building lifecycle stages assessment framework as shown in Figure 2.1.

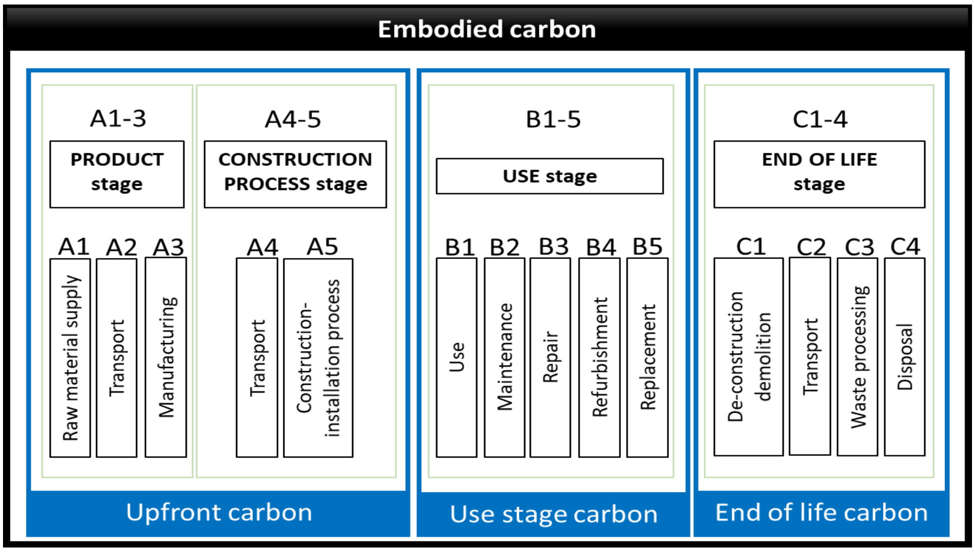

Figure 2.1: Building Lifecycle Stage Embodied Carbon Emission
(Source: Adapted from European Committee for Standardization 2011)

One of the major challenges posed by embodied carbon is that most of it is released early and locked in throughout the lifecycle of a building (Architecture2030 2018; Hillsdon 2019) with its impact hidden from view (Hammond and Jones 2010). This challenge is believed to become exacerbated as the world adds about 230 billion m^2 of floor area to its current floor area between 2017 and 2060 resulting in almost half of the entire carbon emission from new building construction being embodied carbon (UN Environment and International Energy Agency 2017). If this happens, there is a risk for countries to miss their greenhouse gas (GHG) reduction targets in achieving a 1.5ºC world as espoused in the different nationally determined contributions put forward by various governments around the world. For instance, in the UK, the government plans to reduce its GHG emissions economy-wide by at least 68% by 2030 compared to 1990 levels (UK Government 2020) and embodied carbon emission from building construction forms part of this economy-wide GHG emissions especially since the construction sector alone contributes around 7% to the total UK economy and represents 10% of the total carbon footprint of the country (National Federation of Builders Major Contractors Group 2019).

The realisation of the impending danger which the increase in embodied carbon during construction could cause have made researchers and relevant stakeholders to focus attention on tackling same (Wong *et al.* 2014). However, as stated in section 1, most of this attention is on the product stage (Figure 2.1) carbon emission as it is believed that this emission has the greatest impact when it comes to embodied carbon from building construction projects while the construction process stage is being ignored. This is evident given the numerous emission reduction tools that have been created in the last couple of years to simulate embodied carbon of buildings as it relates to various building elements specification to identify which construction material gives the lowest embodied carbon emission (Pomponi *et al.* 2020). But as highlighted by Victoria and Perera (2018) and operationalised by the work of Hong *et al.* (2015), it is clear that some factors like system boundary, data source, methodology, etcetera adopted by these embodied carbon measurement tools can affect their output. Also, some of the tools reviewed in the study by Pomponi *et al.* (2020) supports this claim and the output of some of the tools equally shows the absence of embodied carbon emission related to the construction process stage. Perhaps, this might not be surprising since the architecture of some of the tools does not have data input source for the construction process stage related activities possibly due to the lack of data from site activities such as equipment and plant use and their corresponding carbon emission data (Construction Manager 2021).

With this in mind, it is imperative to establish the presence or lack of it of not only the volume of research related to carbon reduction during construction projects but also to establish the key themes that have been covered or emerging in this area of research. This will ensure that relevant stakeholders' get a glimpse of the likely cause of this 'lop-sidedness' in the embodied carbon research and equally bring to fore possible research path that can be towed in covering this gap in knowledge.

3 Research Methodology

In providing response to the research question posed in Section 1, a systemic review of literature method was adopted since researchers have highlighted its dependability in reducing bias while generating a robust response to a dedicated research question (Mallett *et al.* 2012).

The first task in this study is to select appropriate construction journals that have published carbon reduction research during building construction projects between 2000 – 2021. In doing this, Scopus database was selected due to the fact that the database has enormous archive of engineering, management, business, psychology and construction research publications (Darko and Chan, 2016) and equally owing to its high level of reliability when compared to other databases like Google Scholar and Web of Science (Charef *et al.* 2018). Once Scopus was chosen, keyword search was performed in a bid to identify relevant journals and papers related to the focus of this study as done by other researchers (Deng and Smyth 2013). The keywords selection was a bit challenging. However, an assumption was made on the keywords since as stated by Darko and Chan (2016), one single study cannot in itself address all the likely complexities accompanying research keywords in exploring the subject matter of carbon reduction during building construction projects. Therefore, the two strings of keywords used for this study are as follows:

i) Carbon reduction, carbon emission reduction, greenhouse gas emission
ii) building construction phase or stage

After deciding on the keywords, the journals and papers search was conducted on the 8th of March 2021. The search returned 59 papers from 42 journals and 14 conference proceedings. These journals and conference proceedings included those related to construction and otherwise. Hence, having discovered the limited number of papers available in this research area, it was decided to broaden the scope of the study from just looking at journals alone to then include conference proceedings closely related to the focus of this research. Once this was decided and subject area not related to construction like physics, chemical engineering, medicine, and agriculture were excluded and restricting the search to papers written in English, Scopus returned 46 papers. The final search query used therefore is (TITLE-ABS-KEY(*"carbon reduction"* OR *"carbon emission reduction"* OR *"greenhouse gas emission"*) AND TITLE-ABS-KEY (*"building construction" phase* OR *stage*)) AND PUBYEAR> *1999* AND (EXCLUDE (DOCTYPE, *"ch"*)) AN D (EXCLUDE (SUBJAREA, *"PHYS"*) OR EXCLUDE (SUBJAREA, *"CENG"*) OR EXCLUDE (S UBJAREA, *"COMP"*) OR EXCLUDE (SUBJAREA, *"MEDI"*) OR EXCLUDE (SUBJAREA, *"AGR*

I") OR EXCLUDE (SUBJAREA, *"ARTS"*) OR EXCLUDE (SUBJAREA, *"BIOC"*)) AND (EXCLU DE (LANGUAGE, *"Czech"*))AND (EXCLUDE (SRCTYPE, *"k"*)OR EXCLUDE (SRCTYPE, *"b"*)).

The 46 papers were then scrutinised to ensure they contain only construction related journals and conference proceedings. Upon doing this, 3 papers were removed. Thereafter, they were then checked for duplicate. 1 paper was removed after completing this process. The abstract of the remaining 42 papers was then reviewed to ensure they are relevant to the topic of this present study. On completion, 30 papers from 19 journals and conference proceedings were then selected for further analysis (Table 3.1).

Table 3.1: Journals and Conference Proceedings Including Number of Papers Selected for the Study

Selected Journals and Conference Proceedings	No. of Relevant Papers for the Study
Building and Environment	4
Journal of Cleaner Production	4
Sustainable Cities and Society	3
IOP Conference Series: Earth and Environmental Science	2
Journal of Management in Engineering	2
Sustainability (Switzerland)	2
Journal of Infrastructure Systems	1
Automation in Construction	1
Construction Research Congress 2012: Construction Challenges in a Flat World, Proceedings of the 2012 Construction Research Congress	1
Energy and Buildings	1
Journal of Environmental Management	1
Malaysian Construction Research Journal	1
Construction Research Congress 2005: Broadening Perspectives - Proceedings of the Congress	1
Procedia Engineering	1
Construction Management and Economics	1
Association of Researchers in Construction Management, ARCOM 2012 - Proceedings of the 28th Annual Conference	1
Applied Energy	1
Environmental Engineering and Management Journal	1
International Journal of Life Cycle Assessment	1
Total	**30**

The details of the papers selected for this study were extracted from Scopus to Microsoft Excel for analysis and to answer this study research questions. Also, VOSviewer software was utilised specifically to determine the geographical spread of authors and understand research trend related to carbon reduction during building construction projects. Furthermore, the order of specificity score matrix (Table 3.2) developed by Darko and Chan (2016) upon utilising the widely adopted formula proposed by Howard *et al.* (1987) was used in assessing the contributions of each author relative to their institutions/universities or country. This will equally assist in ranking countries contribution to this important research topic while shedding light on where research in the area of carbon reduction during building construction projects have been largely domiciled.

Table 3.2: Order of Specificity Score Matrix for Papers with Multiple Authors

Number of Authors	Order of Specificity of Authors				
	1	2	3	4	5
1	1				
2	0.6	0.4			
3	0.47	0.32	0.21		
4	0.42	0.28	0.18	0.12	
5	0.38	0.26	0.17	0.11	0.08

4 Findings and Discussion

The aim of this study is to provide insights on the research trend related to carbon reduction during building construction projects in construction journals and conference proceedings through the review of selected papers over the last two decades. The results will be presented in terms of yearly publication trend, geographical spread of authors, and areas of research covered thus far. While interpreting this study results and when drawing conclusions, this should be done bearing in mind the research approach adopted in this study and discussed in the methodology section.

4.1 Annual Publication of Studies

The annual studies related to carbon reduction during building construction projects published within year 2000 and 2021 is as shown in Figure 4.1.

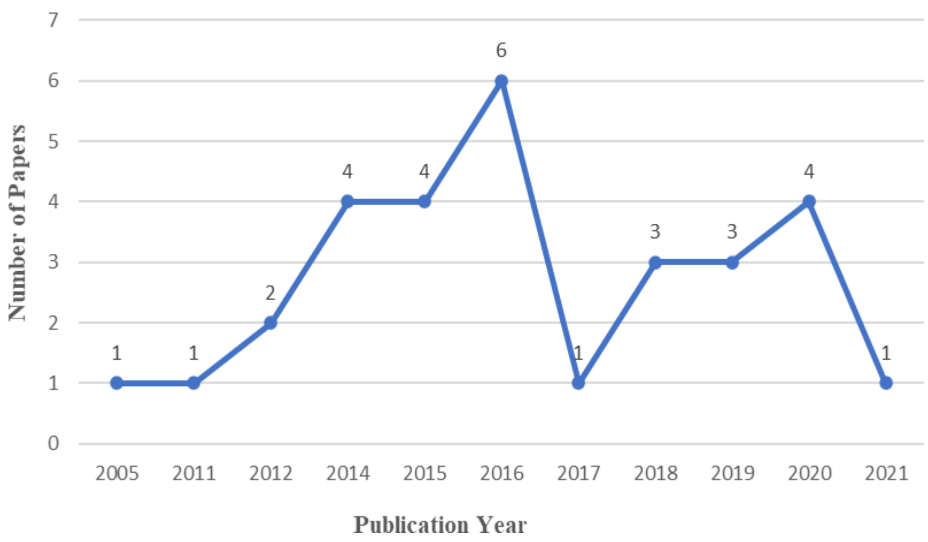

Figure 4.1: Annual Publication of Studies between 2000 - 2021

As seen in Figure 4.1, only one paper was published in the first decade (2000 – 2010) of the period under consideration in this present study. This might be due to the fact that research into carbon emission generally only began to rise significantly in 2007 (Abeydeera *et al.* 2019). Hence, specific research into mitigating carbon during a building construction project might not be a priority.

Perhaps, not until 2014 when IPCC released its *Climate Change* report on the need to guide against the risk portrayed by GHG emission did research into carbon emission spiked moving from 248 papers in a year in 2014 to 479 papers in 2018 alone (Abeydeera *et al.* 2019). This spike was felt within the building construction process carbon emission reduction research as well because within this time period (2014 – 2018), a total of 18 papers were published (see Figure 4.1). Although, there was a dip in research in this area in 2017 and up until now. This concavity might be connected to the increasing use of lifecycle assessment in conducting embodied carbon emission studies as it relates to building construction projects (Huang *et al.* 2018). Hence, the use of lifecycle assessment method has led many scholars (Resch *et al.* 2020; Kong *et al.* 2020) to believe that building construction process carbon emission is relatively low compared to those relating to construction materials. Albeit, with the focus on the building sector to reduce its carbon footprint (Sattary and Thorpe 2016; Sattary and Thorpe 2012) coupled with the rising importance on the need to achieve net zero carbon buildings in 2050 (World GBC 2016), more resources and effort will need to be channelled into research related to understanding carbon emission during building construction projects likewise its reduction. This is extremely necessary due to the fragmented nature associated with building construction process and the non-uniformity in the measurement method of its carbon emission (Hong *et al.* 2015; Wu *et al.* 2019) leading to the general belief that it has a relatively low carbon emission which can be ignored (Wu *et al.* 2019; Sattary and Thorpe 2016). Wu *et al.* (2019) further highlighted that building construction process if considered on the basis of the year taken to complete a building project (which is generally short), has a higher carbon emission.

4.2 Geographical Spread of Authors

The geographical spread of authors who have contributed to research in the area of carbon reduction during building construction projects is presented in Table 4.1. As depicted in Table 4.1, only 15 countries were found to have made contribution to this research area. Authors domiciled in China, US, Australia and Hong Kong (Table 4.1) are the highest contributor based on both their numbers, research papers, and level of contribution (which was calculated using the order of specificity score matrix presented in Table 3.2).

Table 4.1: Geographical Spread of Authors Related to Selected Papers

Country	Institution/Universities	Researchers	Papers	Score
China	12	25	9	7.44
US	10	14	6	6
Australia	3	10	4	4
Hong Kong	1	6	3	2.56
Egypt	1	2	1	1
France	1	5	1	1
Ireland	1	3	1	1
Malaysia	2	2	1	1
South Korea	2	4	1	1
Spain	1	4	1	1
Turkey	1	2	1	1
UK	1	2	1	1
Taiwan	2	2	1	1
Finland	1	4	1	0.62
Iceland	1	1	1	0.38

It was equally observed that there was no inter-continent collaboration but rather the collaboration found was mainly within the same region and this was between China and Hong Kong, and Iceland

and Finland. Although, in perusing some of the papers, the research conducted by Sattary and Thorpe (2016) for instance considered case study from the UK even though the researchers are based in Australia. The lack of inter-continent collaboration could be as a result of the peculiar nature of this research area which mostly have to do with physical construction process and might require researchers to either be present on-site for data collection or obtain data from industry practitioners who might be reluctant to release same based on the seemingly confidential nature of some of the data as industry stakeholder's like to put it. Also, this could be due to the different building regulations applied in various countries requiring different level of compliance when it comes to carbon emission during building construction process. Having said this, with the rising international ratings like LEED (Leadership in Energy and Environmental Design) and BREEAM, probably more collaborative work will be found within this knowledge area as relevant stakeholders strive to achieve these certifications for their work and to position them as champions in climate change mitigation.

Additionally, one striking thing observed in the analysis of the geographical spread of authors as well as paper contribution is the fact that the UK has only one paper from two researchers domiciled in one university. This seems strange because the findings of Abeydeera *et al.* (2019) in their scientometric study on global distribution of research into carbon emissions suggest that UK is the third leading country after China and US to have contributed significantly into carbon emission research. Also, amongst the European Union, the UK's construction sector has been identified as the major contributor to direct carbon emission (Huang *et al.* 2018). This was buttressed by the work of Sattary and Thorpe (2016) who highlighted in their study that the UK government provided funding to some team of researchers in four UK universities to conduct study on material efficiency and the scope of this research according to the investigators include attempt to reduce embodied emissions associated with building construction. Based on the aforementioned, it seems more research and corresponding publications might be required from the UK geared specifically towards carbon reduction during building construction projects.

4.3 Research Covered and Emerging Themes

According to the papers analysed in this study, intense research related to GHG emissions from building construction took off around 2015/16 (Figure 4.2). This research quickly metamorphosised into emissions related to construction process and that associated with construction materials. Although splitted, this might explain the spike in publication regarding carbon reduction during building construction projects in 2016 (see Figure 4.1). However, it seems once researchers discovered that construction materials have higher emissions than other construction process, attention shifted solely to this area of research with scholars working assiduously to find solutions to the rising carbon emission from construction materials. This might explain why 'construction materials', 'climate change', 'emission control', 'carbon reduction' and 'energy efficiency' are co-located and studied together (Figure 4.2). Also, as seen in Figure 4.2, the area of research which have received much attention from 2018 till date are those related to concrete, structural design, ecodesign, and concrete material recycling. Again, these are terms related to efforts in reducing carbon emission from construction material. Furthermore, this corroborates what is in literature as regards the understanding that the reduction of carbon emission from construction materials can be achieved at the design stage (Victoria and Perera 2018; Resch *et al.* 2020) since this is the point where decisions on materials to be used during construction will be chosen.

In addition, most of the studies if not all related to construction process carbon emission as found in the papers analysed have been done in the context of lifecycle analysis or assessment or energy with these keywords appearing for a total of 37 times, therefore, superseding other keywords within these studies. This does not seem surprising because the global carbon emission research conducted by

Abeydeera *et al.* (2019) equally showed that lifecycle assessment as a keyword in carbon emission research appeared 720 times topping all keywords related to research in the area of carbon emission. Hence, it is not surprising that the building construction process stage got side-lined from embodied carbon emission research since most lifecycle study show that the carbon emission associated with it is minimal (Pacheco-Torres *et al.* 2014; Abouhamad and Abu-Hamd 2021) or the construction process stage is even removed completely from the assessment altogether (Atmaca and Atmaca 2015) and as equally observed in some of the embodied carbon emission tools reviewed in the work of Pomponi *et al.* (2020).

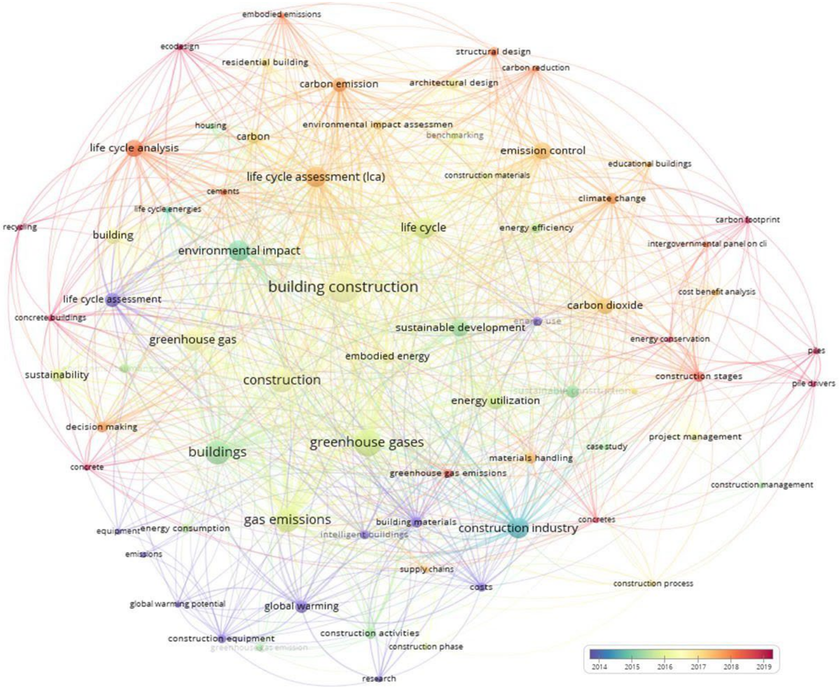

Figure 4.2: Keywords Network of Selected Paper

Another important observation from the papers analysed is that sometimes construction material (product stage, A1 – 3) and construction process stage (A4 – 5) carbon emission seems to be used interchangeably. When some researchers (Atmaca and Atmaca 2015) mention building construction phase carbon emission, they discuss carbon emission related to construction materials mostly. Although, most researchers (Abouhamad and Abu-Hamd 2021; Hong *et al.* 2015; Wu *et al.* 2019; Sattary and Thorpe 2012; Sattary and Thorpe 2016; Gottsche *et al.* 2016) made the distinction between these stages even if some of them end up making recommendations favouring the reduction of carbon associated with construction materials (Sattary and Thorpe 2012; Sattary and Thorpe 2016). Also, within the construction installation phase (A5), there is disparity in literature on what should be included when considering carbon emission sources. Majority of studies (Pacheco-Torres *et al.* 2014; Sandanayake *et al.* 2016; Wu *et al.* 2019) focused on emission related to equipment usage on-site while only few have captured human-related emissions (Hong *et al.* 2015). Some of the reasons given for this omission is that emissions from humans involved in the construction installation process is minimal and should be ignored (Wu *et al.* 2019) or that it is complex to measure. However, based on the work of Hong *et al.* (2015), human-related emissions during a building construction case study were found to contribute almost 5% of the total carbon emission related to the building construction activity.

Based on the aforementioned, the challenge raised by Victoria and Perera (2018) on having a clear system boundary and a defined scope of measurement during lifecycle assessments becomes vital in ensuring that the construction phase carbon emission is adequately captured and mitigated. Therefore, there is a need for researchers to focus efforts on defining a unified system boundary and measurement scope for mapping and measuring carbon emission during building constructions in order to facilitate the proposition of appropriate reduction strategies that can deliver meaningful impact (Wu *et al.* 2019).

Furthermore, from Figure 4.2, it can be observed that 'construction phase', 'supply chain' and 'greenhouse gas emissions' are a bit close together. This suggest that they are likely being studied together during research and might confirm the notion that most of the carbon emission associated with building construction process stage comes from the supply chain. Hence, attention might need to be paid to this speculation when researching or considering carbon reduction options for the emissions linked to the building construction process stage especially since about 99% of emissions related to building construction have been reported to come from supply chain partners (Cross 2021).

Lastly, it should be noted that even though construction process has been an outlier in the scheme of building construction projects carbon emission research, it is vital to be aware that it has been studied closely with global warming in the past (Figure 4.2). Hence, it should not be taken for granted now especially as the world races to achieve net zero carbon buildings.

5 Conclusions and Further Research

The aim of this study is to investigate the claim regarding the side-lining of carbon emission reduction related to building construction process stage and that focus has largely been on construction material carbon reduction. This was done through presenting results obtained in terms of yearly publication of studies, geographic spread of authors and identifying knowledge area covered thus far together with key themes emerging after analysing literatures found in 19 journals and conference proceedings while adopting a systemic review approach. It is important to quickly note that even though the study sets out to examine literatures solely in construction management journals, conference proceedings were included after discovering limited research output in just journals. This effort paid off because important contributions from scholars like Sattary and Thorpe (2012) and Wu *et al.* (2019) would not have been captured.

The findings from this study generally supports the claim investigated with most research actually suggesting carbon reduction tactics related to building construction materials rather than for construction process even if the research was done with the intention of understanding the carbon emission related to the whole building construction. Also, while considerable efforts have been put into understanding the construction process stage carbon emission albeit with some discrepancies in measurement method, not enough literature seem to be found related to research on how to go about reducing this carbon emission. Therefore, researchers and industry stakeholders are urged to focus resources in this direction especially considering the climate change crisis being experienced globally and it is crucial that no stone should be left unturned as the world moves towards net zero emissions.

The findings of this study should be particularly beneficial to researchers and stakeholders with interest in construction carbon reduction as it might shape their outlook towards this field of study.

6 Acknowledgement

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Integrating Users Satisfaction to Support Decisions in Sustainable Developments

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Abstract

With the growing concerns on the environment and the rapid consumption of scarce re-sources, the green building movement and sustainability initiatives started to rapidly grow and stress the importance of sustainable developments and the related benefits under sustainability three dimensions (3D): social, economic, and environmental. Studies showed that current sustainability initiatives and rating systems could not successfully capture the claimed 3-dimensional benefits of sustainability. Most of the sustainability assessment systems and frameworks assign significant weight to environmental credits with an insufficient concentration on social and economic dimensions. Environmental consultants are inclined to follow the client aspirations without balancing user needs and satisfaction to achieve the highest 3D benefits. The study survey showed that lack of knowledge on the impact of green buildings solutions on business value and the lack of public awareness on sustainable developments are two main obstacles towards capturing 3D benefits in the UAE market. The aim of the study is to optimise the sustainability value by integrating the user preferences and levels of satisfaction as a leading role-player in balance with the extent of the scoring points. A survey was conducted to scale the users' satisfaction on several environmental, social and physical factors, wellbeing provisions selected from LEED and WELL building standards. LEED framework was chosen as a foundation of the study. Hence, the results were transformed to user preferences weight and associated with LEED credit options and UNSDG's to support practitioners in the UAE on accreditation decisions towards better sustainability benefits.

Keywords
Sustainability social pillar, UN Sustainable Development Goals (UNSDGs), Users satisfaction,.

1 Introduction

Sustainability assessment systems have vastly spread as they are considered user-friendly, easy to understand tools, and cover most of the substantial aspects of sustainable developments. These well-designed systems support construction practitioners in making sustainability decisions related to different solutions with the help of their precise structure design. Sustainability rating systems have claimed to contribute towards the three dimensions of sustainability through their structure and scoring system (Alyami et al., 2013) (Banani et al., 2016). However, many of the certified building performances were not always align with the desired sustainability targets. Research by Nyikos

(2012) and Hu et al. (2017) highlighted that some certified buildings received no credits for energy reduction or water reduction (Nyikos et al., 2012) (Hu et al., 2017). Various reasons are behind the unsuccessful achievement of the optimal sustainability benefits. The current trend follows the rating systems aimlessly based on the client aspiration as a target rather than developing a specific, project-based sustain-ability strategy causing inefficient use of these frameworks. The rating systems structure also participates hugely if the user does not have a precise sustainability strategy for a project. The rating systems scoring structure gives the more weight to environmental than the social and economic aspects. Following these systems blindly would lead to a level of certification but not the desired impact. The impact of the building on the users is significant, and integrating user comfort and satisfaction side to side with client aspiration drives to achieve further sustainability benefits. Improving the social aspects has proven to impact on and strengthen the business case of sustainable developments through increased productivity and reduced absenteeism (Furr, 2009) (IWBI, 2019). Strengthening the business case in return allows balancing the client aspiration with the desired impact of the sustainable developments. Each project is unique and each occupant or user has a different understanding of what the quality of life in a home or a workplace looks alike. The social satisfaction of the physical and environmental factors within the space like the site location, the design, the building materials, the colours, the thermal comfort, the natural elements within the space, the community, etc., also varies (Raof, 2004) This study aimed to emphasise the social implications and their effect in sustainable developments. For this purpose, this study utilises LEED framework, which is the most widely used green framework in the world and is aimed at creating an appropriate hierarchy of LEED credit options by looking at the corresponding average weights given by the users to aspects from LEED and WELL frameworks. The study then links these aspects back to LEED options and shows the contribution towards the UNSDG's as a guide towards a more holistic approach.

2 Obstacles of Capturing Sustainability 3D Benefits

Sustainability systems have claimed to capture benefits under sustainability three dimensions. However, studies showed that many obstacles preceded that, and the focus was on the accreditation level rather than the potential benefits, as discussed in subsections 2.1 and 2.2.

2.1 Current Studies and Practices in Sustainable Development

The client inspiration of silver, Gold, or Platinum target has always been a starting point for most projects. Environmental consultants are inclined to focus on these aspirations to achieve the certification. Many companies have created charts, listing credits of what are more effortless and costless credits to target. These charts eventually lead to a tick-box exercise without implementing a comprehensive and integrated approach to achieve the desired impact, which was also presented by Park et al. in (2017) (Park et al., 2017) The researchers created an optimisation algorithm to help practitioners obtain the minimum score for the desired certification level and building specifications at a minimum cost. The researchers constructed their algorithm on credits classified under costless-Easy, costless-Hard, cost-Easy, and cost-hard categories. Information on each credit cost was derived from the study of 3 certified projects in Korea. However, this algorithm has a fixed unit price which makes it challenging to adopt in different regions. Seeking to achieve the minimum credits score required for the desired level at the least cost does not always align with sustainability goals.

Many researchers have tried to build human knowledge and experience in different models using the cognitive approach. These models aimed to work as decision making support tools and to target the three-dimensional benefits. Researchers have acknowledged multi-criteria decision-making method (MCDM) as a suitable approach for sustainability. They have employed Analytical Hierarchy Process (AHP) as the most common and powerful MCDM method (Boggia and Cortina, 2010)

(Saaty, 2000). AHP is considered a decision making analysis tool in areas like social, economic, and management (Yu, 2002). In 2015, Nilashi et al. used the AHP to determine the experts' preference of different criteria and alternatives and build the fuzzy logic model (Nilashi et al., 2015). The model helps assess the existing building by implementing human knowledge and experience from a social, eco-nomic, and environmental perspective. Attallah (2014) utilised (MCDM) to reach a systematic pattern in the credits' selection process, and its relation to decisions on different sustainability-related solutions (Attallah, 2014). In 2017, Attallah et al. found that relying on intuition is the most effective method while using these rating systems (Attallah et al., 2017). Their study used (LEED and QSAS) as two sustainability rating systems at the pre-design stage of the project's lifecycle, showed the experts had used no systematic approach. At this phase of the project, there will be many variables and fewer measures to support the sustainability decisions and preferences. The researchers used Electre III to optimise experts' cognitive approach as a multi-criteria decision analysis method. Although researchers have looked into expert preferences, clients and end-users preferences, their specific hierarchy assigned minor importance to users satisfaction.

2.2 Sustainability Assessment Systems and Scoring Structure

The sustainability assessment systems and scoring structure is a cumbersome contributor to that argument. The rating systems contribution to sustainability three dimensions was analysed and studied by Awadh in 2017 (Awadh, 2017). BREEAM International 2016 and LEED V4 are widely proven and internationally used systems (BRE Global, 2016) (USGBC, 2019). Figure 1 and Figure 2 show how these sustainability systems assign most of their credits weight and scores towards the environmental pillar, fewer towards social and the least towards the economic pillar. The weight of LEED and BREEAM social-related credits is 12% and 16%, respectively (Awadh, 2017).

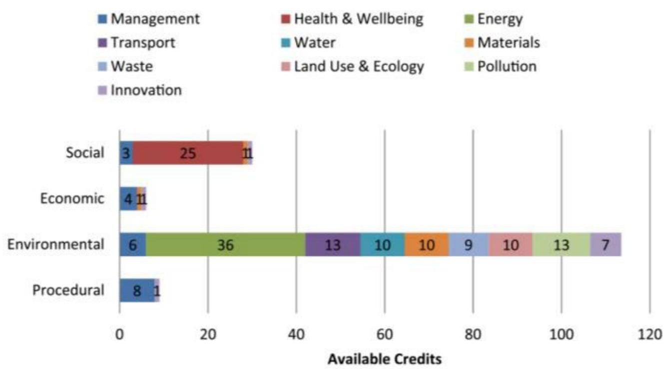

Figure 1. BREEAM International 2016 credits weighting of Environmental, Social and Economic Pillars, (Awadh, 2017)

The occupancy and operation profile variations are somehow neglected in LEED. Moreover, very few credits include the user survey and with little impact on the score. It is difficult to assess the building performance and the implications of the sustainability decisions made by the consultants without retrieving the information from the occupied project to look at the whole life cycle and reflect on the recent findings. Building occupants satisfaction and preference should not be abundant. They improve the building contribution towards more social and economic benefits.

Figure 2. LEED NC V4 credits weighting of
Environmental, Social and Economic Pillars, (Awadh, 2017)

3 Social Satisfaction and Perception of a Place

In the 20th century, the business cost was considered much higher than the energy cost and yet more urgent to improve productivity in the workplace. Today, both costs are close with higher energy consumption and the increased use of scarce natural resources (Raof, 2004). Sustainable development could achieve the balance between the two. However, up till 2019, the Green Building Council believed that there is still a lack of understanding about retaining employees and increasing productivity with healthy design practices in the physical environment. As each project is unique, the environmental consultant and client should set a sustainability plan or a sustainability strategy at the early phase of this particular project. At that stage, KPI's or indicators measure the achievement against that goal and monitor any change in a specific category over the project lifecycle. Indicators for energy usage and other criteria are more approachable, while occupant satisfaction indicators are complex to define and consider (Raof, 2004). Each building is different, and each occupant and building professional has a different opinion about the comfortable place, whether it is a workplace or a home. Roaf, S. et al, (2003) called it the perceived quality of life's factors (QOL) in building and named these indicators into building-level indicators, and personal indicators (Raof, 2004). Occupants conceive the quality of life through different environmental and social factors in space differently. Palich and Edmonds (2013) have also defined social sustainability as sustaining a healthy community and its diverse social relationships and supporting community and wellbeing through the physical, cultural, and social places, making the engagement with inhabitants of the place of a great value (Palich and Edmonds, 2013).

4 Social User Wellbeing and Satisfaction Implementation to Improve Business Case

Roaf et al. (2004) mentioned that linking health and sustainability to business has become increasingly important to people with the rising awareness about good indoor environmental quality and its relation to user satisfaction and productivity (Raof, 2004). UKGBC has connected users' comfort and happiness to a positive impact on clients business as a result of more productivity. ”UKGBC the Wellbeing lab: Retails” was built in 2018 based on meeting the customers buying needs when visiting the physical shopping space as a must for any business to stand apart from other competitors (UKGBC, 2018). The target was to tackle successful healthy design features towards happier employees yet happier customers. The framework of the study was designed under three categories; The environmental or physical characteristics that can be measured like lighting, thermal etc. The experience, which refers to employee and customers satisfaction and perceptions of the space. The economics, which refers to employee's turnover, absenteeism and value drivers such as sales and brand. Earlier in 2016, UKGBC built the" Offices Lab" based on the same belief (UKGBC, 2017). Organisations like M&S has also conducted semi-structured interviews and survey to identify employee preferences and outline key issues to implement in the current and future business. Moreover, with the rapid emergence of this concept, GRESB Real Estate has added Health and wellbeing Module in 2016 under the scheme of promoting employees' health and wellbeing and promoting health and wellbeing through products and services (GRESB, 2016). Having such a framework has allowed to include health and wellbeing in assessment and peer benchmarking similarly to the main Real Estate. The main concept behind the two areas is the impact of specific decisions and actions in relation to costs and performance when promoting the employees' health and wellbeing responsible for the entity through providing certain products and services. Prior to GRESB in 2014, a new official framework called Building WELL Standards (WELL V1) was launched by the International Well Building Institute (IWBI) to focus on the social pillar of sustainability and buildings direct impacts on the user's health and wellbeing (IWBI, 2019). WELL V2 pilot was released in 2018 as the second version of WELL Building Standards. The aim was to prioritise human wellbeing and positively impact people over the whole building life cycle by maintaining health, happiness, and wellbeing. WELL is the first rating system to quantify factors like nourishment and mind and get live feedback at the building's operational phase (IWBI, 2019).

5 Research Methodology

The selection of the methodology was due to different factors. The need to find controversial and diverse participants is one factor that is hard to achieve via other methods. In addition, the sampling is challenging. It is difficult to find information about anonymous people. Therefore, the survey was circulated on-line to involve employees and residents of the UAE using the Linkedin database via emails. The questions seek the user's perception of several environmental and physical factors, wellbeing initiatives and nourishments.

The first three survey results were used to test the survey design, the questions and the content, two were from the educational field and one from the construction industry. All amendments were implemented accordingly before circulating the survey. Sixty-five (65) participants attempted and completed the survey. The survey consisted of 5 sections, including the introduction and a total of eight (8) survey questions. A prescribed explanation was provided in the introduction section to give context to the participants and information about the survey time needed, confidentiality and security. Section 2 included questions about general information. Section 3, 4 and 5 included questions that required participants to scale their assessment to different environmental and wellbeing factors in buildings (5 is so important-1 is not important at all). Section 2 also asked to define the main obstacles towards capturing sustainability 3-dimensional benefits in the UAE market.

6 Findings and Discussion

The following two subsections 6.1 and 6.2 explained how the data was analysed, processed then implemented. As a result, the study linked the aspects and their average weights, the credit options and the UNSDG's in a qualitative method based on the understanding of each credit option and its intent. Having these data at the early phase of the project helps sustainability experts to look at what is more valuable to improve the social implication rather than reaching more scoring points.

6.1 Pre-possessing the Data

A weight was assigned to each credit option based on the end user preferences to different aspects from the survey questionnaire results. These aspects covered a breadth of social, environmental, and physical characteristics of the space inspired by LEED and WELL frameworks. The preferences given by the users were transferred to average user preferences weight in three steps of calculations to reach the final value. The value represents the average weight of an aspect given by users and reflects the users' perception of these credits-related aspects.

6.2 Linking the Average Weight to The Related Credit Option

The average weights given by the users were assigned to LEED credit options. Figures 03, 04, 05, 06, 07, 08, and 09 show the final average weight assigned to each credit option under the listed categories. The factors were linked to LEED credit options in a qualitative method based on understanding LEED and WELL credits requirements and intents. Each aspect or factor was given a code to simplify retrieving this information when needed and to be able to integrate it within the structure.

Figures 3 and 4 refer to the average user weight given to different aspects and their relation to LEED Indoor Environmental Quality credits. Although LEED assigned a low score to credits EQc7 and EQc8 (Daylight and Quality views) of 1 point to Quality views and 1-3 points to Daylights, the results show that credits EQc7 and EQc8 (Daylight and Quality views) were given the highest importance by users, which reflects the highest level of satisfaction and comfort with an average of 0.94. EQp1 (Min Indoor Air Quality Performance), EQc1 (Enhanced IQA Strategies option1 and option 2) during occupancy phase, EQc2 (option1 and option 2), EQc3 (related to during construction and pre-occupancy phase), and EQc4 (option1 and option 2), all came second with an average of 0.93. Reduced exposure to hazardous building material ingredients average weight was 0.91. Thermal comfort control in the UAE was given the importance of 0.90, while Acoustical comfort: sound barriers, absorption, masking and Lighting personal control, were assigned 0.85 and 0.84, respectively. Users gave 0.88 to a smoke-free environment, and it was linked to EQp2. Operable windows was similar to Lighting personal control with 0.84. Operable window was linked to EQc1 option 2 (additional enhanced IAQ Strategies). The results show the users' perception and satisfaction different to different credits as oppose to LEED credit weighting system. LEED awards more points to credits and strategies with more significant positive impact. However, under the Indoor Environmental Quality category, LEED has not differentiated between these credits and has assigned mostly a score of 1 point.

Indoor Environmental Quality							
UNSDG's		**Indoor Environmental Quality**			**Inspired by LEED**	**Inspired by WELL**	**Average Weight (w)**
UNSDG 3- UNSDG7-UNSDG8		EQp1	Min Indoor Air Quality Performance		UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93
UNSDG 3- UNSDG7-UNSDG8		EQp2	Environmental Tobacco Smoke Control		UCS-E14-Smoke free environment		0.88
UNSDG 3-UNSDG8		EQc1	Enhanced Indoor Air Quality Strategies	**Option 1.** Enhanced IAQ strategies **1 point**	UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93
				AND/OR Option 2. Additional enhanced IAQ strategies **1 point**		UCS-IN02-Operable Windows	0.84
UNSDG 3-UNSDG8		EQc2	Low Emitting Materials	**Option1.** Product category Calculations **(1-3 points)**	**UCS-E11**-Reduced exposure to hazardous building material ingredients **UCS-E12**-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.91-0.93
				Option 2. Budget Calculation Method **(1-3 points)**	**UCS-E11**-Reduced exposure to hazardous building material ingredients **UCS-E12**-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.91-0.93
UNSDG 3-UNSDG8		EQc3	Construction Indoor Air Quality Management Plan	**1Points**	UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93
UNSDG 3-UNSDG8		EQc4	Indoor Air Quality Assessment	**Option 1.** Flush-out. Path1. Before Occupancy **1 Point**	UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93
				OR Option 1. Flush-out. Path2. During Occupancy **1 Point**	UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93
				OR Option 2. Air testing **2 points**	UCS-E12-Air Quality: Low Co2 and other pollutants- High ventilation rates		0.93

Figure 3. Average user preference weights of aspects related to Indoor Environmental Quality category and credits contribution to UNSDG's

Indoor Environmental Quality						
UNSDG's	Indoor Environmental Quality			Matching LEED credits	Matching WELL credits	Average Weight (w)
			Thermal comfort Design Option 2. ISO and CEN Standards **1Point**	UCS-E09-Thermal comfort-personal control		0.9
			Thermal comfort Design Option 1. ASHRAE Standard 55-2010 **1Point**	UCS-E09-Thermal comfort-personal control		0.9
UNSDG 3- UNSDG7-UNSDG8	EQc5	Thermal Comfort	**Thermal comfort Control**	UCS-E09-Thermal comfort-personal control		0.9
			Option 1. Lighting control **1Points**	UCS-E10-Lighting- personal control		0.84
UNSDG 3- UNSDG7-UNSDG8	EQc6	Interior Lighting	**And/OR Option 2.** Lighting quality **1 point**			
			Option 1. Simulation: Spatial Daylight Autonomy **55%-2points**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
			Option 1. Simulation: Spatial Daylight Autonomy **75%-3points**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
			Option 2. Simulation: Illuminance Calculations **75%-1 point**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
			Option 2. Simulation: Illuminance Calculations **90%-2 point**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
			Option 3. Measurement **75-2 points**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
UNSDG 3- UNSDG8	EQc7	Daylight	**Option 3.** Measurement **90-3 points**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
UNSDG 3- UNSDG8	EQc8	Quality Views	**1Point**	UCS-IN01- Layout design - Aesthetics- Connecting to nature: views of nature, daylight, proximity to windows		0.94
UNSDG 3- UNSDG8	EQc9	Acoustic Performance	**1Point**	USC-E13-Acoustical comfort: sound barriers, absorption, masking		0.85

Figure 4. Average user preference weights of aspects related to Indoor Environmental Quality category and credits contribution to UNSDG's

Figure 5 refers to the average user weights of aspects and factors related to LEED Location and Transportation credits. Access to outdoor green spaces, recreational fields or courts scored the highest, with an average weight of 0.87. This was followed by Proximity to walkways with 0.86. These two aspects were connected to LTc1 credit (LEED for ND Development) and Access to the gym and other physical activity spaces. The latter achieved 0.79 as a given average weight. Proximity to public transportation scored 0.85 as close to Proximity to different uses with a score of 0.84. The two factors were linked to Access to Quality Transit and Surrounding Density and Diverse Uses, respectively.

The results represent that the users did not assign the maximum weight to these two credits, unlike LEED rating system. Proximity to bicycle network was given 0.70. However, users assigned low importance to showers on-site as a condition and have assessed Access to showers and cycle storages as the least important with an average of 0.64. The Users within the region have not connected these aspects directly to their area of comfort.

Location & Transportation						
UNSDG's	Location & Transportation			Inspired by LEED	Inspired by WELL	Average Weight (w)
UNSDG 11- UNSDG13-UNSDG15	LTc1	LEED for ND Development Location			UCS-E03 Proximity to walkways	0.86
					UCS-E06 Access to outdoor green spaces, recreational field or court	0.87
			Certified / silver / Gold / Platinium		UCS-E08 Access to Gym, other physical activity spaces	0.79
UNSDG 11- UNSDG13-UNSDG15	LTc2	Sensitive Land Protection	**1Point**			
UNSDG 11- UNSDG13-UNSDG15	LTc3	High -Priority Site	**Option 1.** Historic district **1 point**			
			OR Option 2. Priority designation **1 point**			
			OR Option 3. Brownfield remediation **2 points**			
UNSDG 7- UNSDG8-UNSDG9-UNSDG 11- UNSDG 12-UNSDG13-UNSDG14-UNSDG15	LTc4	Surrounding Density and Diverse Uses	**Option 1.** Surrounding density **2 points**	UCS-E01 Proximity to different uses		0.84
			Option 1. Surrounding density **3points**			
			And/OR Option 2. Diverse uses **1points**			
			Option 2. Diverse uses above 8meter **2points**			
UNSDG 7- UNSDG8-UNSDG9-UNSDG 11- UNSDG 12-UNSDG13-UNSDG14-UNSDG15	LTc5	Access to Quality Transit	for projects with multiple transit types (bus, streetcar, rail, or ferry) **1point**	UCS-E02 Proximity to public transportation		0.85
			for projects with multiple transit types (bus, streetcar, rail, or ferry) **3points**			
			for projects with multiple transit types (bus, streetcar, rail, or ferry) **5points**			
			for projects with commuter rail or ferry service only **1point**			
			for projects with commuter rail or ferry service only **2point**			
			for projects with commuter rail or ferry service only **3point**			
UNSDG3-UNSDG 7-UNSDG9-UNSDG 11- UNSDG 12-UNSDG13-UNSDG14-UNSDG15	LTc6	Bicycle Facilities	**1Point**	UCS-E04 Proximity to bicycle network		0.7
				UCS-E05 Access to showers and cycles storage		0.64
UNSDG13-UNSDG14-UNSDG15-UNSDG16	LTc7	Reduced Parking Footprint	**1Point**	UCS-E07 Availability of Car parking slots		0.8
UNSDG3-UNSDG 7-UNSDG9-UNSDG 11- UNSDG 12-UNSDG13-UNSDG14-UNSDG15	LTc8	Green Vehicles	**Option 1.** Electric vehicle charging **1Point**			
			OR Option 2. Liquid, gas, or battery facilities **1Point**			

Figure 5. Average user preference weights of aspects related to Location & Transportation category and credits contribution to UNSDG's

Figures 6 and 7 present the average user weights of different factors and their relation to LEED Material & Resources and Innovation categories. Reduced exposure to hazardous building material ingredients was one aspect that fell under Materials & Resources credit with averages of 0.91. This aspect was linked to credit MRc4. However, LEED assigns credit MRc4 a score of 1 point. The Green Cleaning and green products are still not perceived as highly essential and were given 0.78 and associated under Innovation credit.

Figure 8 represents the average user weights of aspects related to LEED Site Selection credits. Access to outdoor green spaces, recreational fields or court was associated with credits SSc2, SSc3, and SSc4 with an average of 0.87. Finally, aspects related to Nourishment, Wellbeing Initiatives and Layout Design- Aesthetics areas consisted part of the study. Figure 9 presents aspects that were inspired by WELL standards to improve the social implications of sustainable developments. The focus is to consider the additional categories labelled as great contributors to user satisfaction and comfort in an equally effective manner and as essential to implement through the accreditation process. Results show that all the aspects were almost equally important to the users. However, Access to healthy food with pricing incentives and Office interior layout: workstations configuration and density achieved the highest with an average of 0.85 and 0.84, respectively.

6.3 Linking LEED Credits to UN Sustainability Development Goals (UNSDG’s)

The United nation 17 sustainable development goals (UNSDG's) were created in 2012 in Rio de Janeiro Conference on Sustainable Development and were implemented in the 2030 Agenda to be taken as commitment and prompt implementation by each country at different levels (United Nations, 2015). Participating in the achievements of these goals is essential to overcome the current environmental, social and economic challenges by considering all 3D aspects through the credits selection process. It is crucial to understand each LEED credit, its related aspects and the additional proposed aspects towards the 17 UN sustainable development goals (UNSDG’s) to support the experts and better engage the clients. Thus, relying on the understanding of the credit intent and requirements on the one hand and each of the UN Sustainability Development Goals will achieve the desired aim. At the early stage of the project, this understanding is crucial to bring the client on board with the rest of the sustainability team members. As each organisation adopts a strategy to fulfil its vision, creating the link to the UN sustainable development goals attracts clients to work on the desired aimed impact rather than the accreditation level. This step is crucial to balance the users’ satisfaction and comfort with client aspiration and goal.

These relations were made based on understanding both the UN sustainable development goals and LEED credits and options requirements. Credits of LEED framework that have proven to contribute to users’ satisfaction and comfort at various levels and the aspects from WELL framework, all were linked back to the UNSDG’s considering credits’ need and intent and the possibility of supporting the achievement of UN sustainable development goals. The association was made based on the direct influence on UNSDG’s only instead of direct and indirect as most of the credits are connected and intersected in a way or another. Figures 3, 4, 5, 6, 7, 8 and 9 show LEED credits under LEED categories and their contribution to the UNSDG’s achievement under the first column. Under LEED Innovation category, some variations in the contribution to UNSDG’s related to each innovation option were presented in Figure 7, as there are some disparities between Exemplary performance credits under Option 3, Pilot credits in Option 2 and Innovation in Option 1.

Material Resources							
UNSDG's		**Material Resources**			**Inspired by LEED**	**Inspired by WELL**	**Average Weight (w)**
UNSDG3-UNSDG 8-UNSDG9-UNSDG 12- UNSDG13-UNSDG14-UNSDG15		MRp1	Storage and Collection of Recyclables				
UNSDG3-UNSDG 8-UNSDG9-UNSDG 12- UNSDG13-UNSDG14-UNSDG15		MRp2	Construction and Demolition Waste Management Planning				
UNSDG 8-UNSDG9- UNSDG 12-UNSDG13-UNSDG14-UNSDG15		MRc1	Building Life-Cycle Impact Reduction	**Option1.** Historic Building Reuse **(5points)**			
				OR Option2 Renovation of Abandoned or Blighted Building **(5 points)**			
				OR Option 3 Building and Material Reuse 25%-**2 points** 50%-**3points** 75%-**4points**			
				OR Option 4. Whole Building Life-Cycle Assessment **(3 points)**			
UNSDG 8-UNSDG9- UNSDG 12-UNSDG13-UNSDG14-UNSDG15		MRc2	Building Product Disclosure and Optimisation-EPD	**Option 1** Environmental Product Declaration **(1point)**			
				AND/OR Option2. Multi-Attribute Optimization **(1 point)**			
UNSDG 8-UNSDG9- UNSDG 12-UNSDG13-UNSDG14-UNSDG15		MRc3	Building Product Disclosure and Optimisation-Sourcing of Raw Materials	**Option1:** Raw material source and Extraction Reporting **(1 point)**			
				OR Option2: Leadership Extraction Practices Possible **(1Points)**			
UNSDG3- UNSDG 12-UNSDG13-UNSDG14-UNSDG15		MRc4	Building Product Disclosure and Optimisation-Material Ingredients	**Option1.** Material Ingredient Reporting **(1point)**	UCS-E11-Reduced exposure to hazardous building material ingredients		0.91
				AND/OR **Option2.** Material Ingredient Optimization **(1 Point)**	UCS-E11-Reduced exposure to hazardous building material ingredients		0.91
				AND/OR **Option3.** Product Manufacturer Supply Chain Optimisation**(1 Point)**	UCS-E11-Reduced exposure to hazardous building material ingredients		0.91
UNSDG 12- UNSDG13-UNSDG14-UNSDG15		MRc5	Construction and Demolition Waste Management	**Option1.** Diversion Path 1. Divert 50% and three material streams **(1 point)**			
				OR Option1. Diversion Path 2. Divert 75% and Four material streams **(2 point)**			
				OR Option2. Reduction of Total waste material **(2 point)**			

Figure 6. Average user preference weights of aspects related to Material & Resources category and credits contribution to UNSDG's

Innovation							
UNSDG's		Innovation			Inspired by LEED	Inspired by WELL	Weight (w)
UNSDG7-UNSDG 8-UNSDG9-				Option 1. innovation 1 point	UCS-E16 Indoor Air Quality- Green Cleaning		0.78
UNSDG 2- UNSDG3-UNSDG6-UNSDG7-UNSDG8-UNSDG9-UNSDG11-UNSDG12-				And/Or Option 2. pilot 1 point			
UNSDG8-UNSDG9-UNSDG11-UNSDG12-UNSDG13-UNSDG14-UNSDG15		INc1	Innovation	And/Or Option 3. additional strategies 3 points			
\		INc2	LEED Accredited Professional	1Point			

Figure 7. Average user preference weights of aspects related to Innovation category and credits contribution to UNSDG's

Site Selection							
UNSDG's		Sustainable Site			Inspired by LEED	Inspired by WELL	Average Weight (w)
UNSDG3-UNSDG 7-UNSDG9-UNSDG 11-UNSDG 12-UNSDG13-UNSDG15		SSp1	Construction Activity Pollution Prevention				
UNSDG 11-UNSDG15		SSc2	Site Assessment	1Point	UCS- E06 Access to outdoor green spaces, recreational field or court		0.87
UNSDG3-UNSDG 11-UNSDG 12-UNSDG15		SSc3	Site Development-Protect or Restore Habitat	Preserve 40% of the greenfield area AND Option1. On-site Restoration (2points)	UCS- E06 Access to outdoor green spaces, recreational field or court		0.87
				OR Preserve 40% of the greenfield area AND Option2. On-site Restoration (1points)	UCS- E06 Access to outdoor green spaces, recreational field or court		0.87
UNSDG8-UNSDG 11-UNSDG 13-UNSDG14-UNSDG15		SSc4	Open Space	1Points	UCS- E06 Access to outdoor green spaces, recreational field or court		0.87
UNSDG3-UNSDG 7-UNSDG 13-UNSDG14-UNSDG15		SSc5	Rain Water Management	Option1. Percentile of Rainfall Events. Path1. 95th Percentile (2 points)			
				OR Option1. Percentile of Rainfall Events. Path2. 98th Percentile (3 points)			
				OR Option1. Percentile of Rainfall Events. Path3. Zero lot line projects only-85th Percentile (3 points)			
				OR Option2. Natural Land Cover Conditions (3 points)			
UNSDG3-UNSDG 7-UNSDG 12-UNSDG13		SSc6	Heat Island Reduction	Option1. Nonroof and roof (2 points)			
				OR Option2. Parking under cover (1 points)			
UNSDG 7- UNSDG 9		SSc7	Light Pollution Reduction	Uplight Option1. BUG rating Method			
				OR Uplight Option2. Calculation Method			
				AND Lighttrespass Option1. BUG rating method			
				OR Lighttrespass Option2. Calculation Method			
				AND Internally Illuminated Exterior Signages			

Figure 8. Average user preference weights of aspects related to Sustainable Sites and credits contribution to UNSDG's

Health & Wellbeing in Buildings- Inspired by WELL Framework		Average Weight (w)	Health & Wellbeing in Buildings- Inspired by WELL Framework		Average Weight (w)	Health & Wellbeing in Buildings-Inspired by WELL Framework		Average Weight (w)
UNSDG's	Wellbeing Initiatives		UNSDG's	Layout design - Aesthetics		UNSDG's	Nourishment	
UNSDG3	UCS-WB06 Financial rewards for physical activity-incentives in your organisation	0.76	UNSDG3- UNSDG8	UCS- IN03 Access to indoor common space	0.78	UNSDG1-UNSDG 2	UCS-WB01 Access to healthy food with pricing incentives	0.85
UNSDG3- UNSDG4	UCS-WB07 Availability of education on common mental health conditions: depression, anxiety, stress and substances use	0.79	UNSDG3- UNSDG8	UCS-IN04 Availability of social interaction space in Office- e.g., cafe'	0.82	UNSDG4	UCS-WB02 Access to Nutrition Education	0.77
UNSDG5	UCS-WB08 Availability of education on mental health distress (how to identify emotional distress and how to respond)	0.77	UNSDG3- UNSDG8	UCS-IN05 Office interior layout: workstations configuration and density	0.84	UNSDG2	UCS-WB03 Nutritional labeling and information on food for sale	0.83
UNSDG3	UCS-WB09 Availability of an on-site childcare facility with a policy supporting breaks for breastfeeding in your organisation	0.79	UNSDG3- UNSDG8	UCS-IN06 Indoor design elements: natural plants and water features, music, artworks,..etc	0.82	UNSDG1-UNSDG 3	UCS-WB04 Opportunities to produce food on-site: edible landscaping, fruit, herbs, green Houses,..etc	0.71
UNSDG3	UCS-WB10 Proximity to free on-demand health service facility or through digital provider in your organisation	0.76	UNSDG3- UNSDG8	UCS-IN07 Adjustable workstations to sit or stand	0.78	UNSDG4	UCS-WB05 Availability of education on dietary habits and eating behaviors	0.76
UNSDG9	UCS-WB11 Productivity through measures of hours worked in your organisation	0.78	UNSDG3- UNSDG8	UCS-IN08 Indoor visual privacy in Office	0.77			
UNSDG3- UNSDG6	UCS-WB12 Water quality : filtration system	0.88	UNSDG3- UNSDG8	UCS-IN09 Indoor calming colors, textures, forms	0.81			

Figure 9. Average user preference weights of aspects related to Layout Design- Aesthetics, Nourishment, and Wellbeing Initiatives and its contribution to UNSDG's

7 Conclusions and Further Research

The study aimed to optimise the sustainability value by creating an innovative method to sup-port the environmental consultants with their decisions on different sustainability solutions. These decisions are essential to be looked at from the perspective of the desired impact of that particular project than its accreditation level and achieved score. However, the lack of aware-ness of the social implications of these decisions and the structure of sustainability assessment frameworks have hindered capturing the potential sustainability benefits. The literature showed that organisations like M&S have tried to include user perceptions to empower their business case. Moreover, researchers like Attalah, et al. in (2017) created a specific hierarchy between clients, experts and end-users preferences. However, the researchers gave the end-user satisfaction the least weight. Therefore, the study has created an innovative process of three steps to implement the users' comfort and satisfaction as they were proven to increase productivity and contribute towards more social and economic benefits.

The first step was to survey end-users to generate a broader understanding of credit's contribution to user comfort and satisfaction. The survey consisted of 5 sections, including the introduction and a total of eight (8) survey questions. Sixty-five 65 participants from the UAE region have filled a questionnaire and assessed various environmental, physical, and wellbeing factors from 1 to 5, where 5 is highly important. All aspects were inspired by LEED and WELL frameworks categories and aspects. The study helped to understand users' perception of these factors and aspects better through their assigned average weight. Users gave higher importance to some environmental factors, reflecting the improvement in users' awareness and understanding of the impact of these factors on users' health in an indoor environment. Factors inspired by WELL standards related to Nourishment, Wellbeing Initiatives and Layout Design-Aesthetics areas were also part of the study to improve the social implications of sustainable development. Results showed that most of these aspects were assigned almost equal importance yet equal average weight to users satisfaction and comfort. Access to healthy food with pricing incentives and Office interior layout: workstations configuration and density were crucial to users. The next step was linking these aspects and the related average weight from the survey back to LEED credits. The last step was to connect credits from step one to UN sustainable development goals (UNSDG's) to prioritise credits contribution to a particular goal. These steps help support practitioners in the UAE on LEED accreditation decisions by emphasising the social aspect and integrating it as a lead role through the credits selection process. The study survey showed two main obstacles towards capturing 3D benefits in the UAE market; the lack of knowledge on the impact of green buildings solutions on business value and the lack of public awareness on sustainable developments. By emphasising the social dimension, sustain-able developments will strengthen the business case by aligning the client aspiration with the desired impact and contribution towards UN sustainable development goals (UNSDG's).

A more intensive study is undergoing to expand the work and acquire more data of additional factors crucial to the client, the sustainability consultant and the occupants. The information will then be implemented to support achieving the potential sustainability benefits under the three sustainability aspects.

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Towards Automation of Sustainable Green Building Materials in India

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Abstract
The AEC (Architecture Engineering and Construction) industry has had a reputation for being a major contributor to negative effects on the environment. Hence, the need for development of sustainable buildings is increasing. Sustainability in the construction industry has the utmost potential to effect change in current construction practices. In this paper, two stage assessment of material is conducted in one stage IGBC green materials rating system is developed in BIM for the ease in process and in second stage an analytical tool to assess the eco-efficiency of building facade materials is developed (ECO-DEA Green rating system-EDGRS). This two-stage process assesses sustainable criteria and optimization of material selection aspects and process automation of material selection through BIM approach in both stages respectively. The ECO-DEA tool evaluates the eco- efficiency of façade material by using data envelopment analysis (DEA), a linear programming-based mathematical approach. Life-cycle assessment (LCA) and life-cycle cost (LCC) is used to rank material alternatives. It provides a holistic approach combining two pillars of sustainability, economy and ecology which gives complete information to the decision makers. It is followed by quantitative cradle-to-gate approaches, since they cover multiple environmental criteria. Most of the important decisions regarding green building construction are taken before the construction process starts. The created framework is an expandable automation assessment of sustainable criteria and green building rating system in India. It offers a vital guidance to the decision makers to evaluate alternative construction material selection.

Keywords

Building Information Modelling (BIM), Green BIM, Sustainability.

1 Introduction

The AEC industry is known for being a key contributor to adverse effects on the environment. Nowadays, due to the deteriorating environment, the focus is shifted to improve and protect natural resources. So, the concept of green buildings is introduced to tackle environmental challenges. The advantages of green buildings are:

- Efficient usage of water, energy and other resources
- Optimizing energy efficiency and encouraging the use of renewable energy.
- Conserving natural resources and minimize the generation of waste.
- Maintaining a good indoor environment by using non-toxic, ethical, and sustainable materials.
- Considering the quality of life of occupants in design, construction, and operation.

A slight increase in upfront costs of about 2% to support sustainable design, on average, results in life cycle savings of approximately 20% of total construction costs; which is more than ten times the initial investment (Kats, et al., 2003).

Nowadays, the extensive use of computers, architecture and engineering software demonstrates their tremendous role in the architecture, engineering and construction (AEC) industry. Building Information Modelling (BIM) can support the collaboration between various stakeholders throughout the project lifecycle by providing facilities to insert, extract, update or modify information in the BIM model. BIM tools offer the AEC industry the ability to facilitate and ease design, construction management, and other activities related to a construction project (Motawa, 2013).

Currently, for green building ratings, the traditional computer-aided design (CAD) drawings are submitted and used for evaluation. For the evaluation of category under materials and resources, the calculations are entered into the template by calculating the quantities for Bill of Quantities (BOQs) or manually from CAD drawings. If there are some variations in the drawings then the evaluator has to manually change the values in the template, which sometimes might cause errors.
There are several international organisations which have developed the green building rating system based on the type of construction and performance of the building. The oldest is BREEAM (Building Research Establishment's Environmental Assessment Method) was launched in 1990 in United Kingdom, followed by LEED (Leadership in Energy and Environmental Design) in United States in 1998. Some of the green building agencies in India are Indian Green Building Council (IGBC), Leadership in Energy and Environmental Design (LEED) India, Green Rating for Integrated Habitat Assessment (GRIHA), Energy Conservation for Building Code (ECBC)Excellence in Design for Greater Efficiency (EDGE).

The BIM model can be 4D model by connecting model elements to time schedules, and it can be 5D model by integrating cost estimation with model components. Several researches have been conducted in the areas of construction optimization and decision-making, leading to the development of a number of optimization models using a variety of approaches. In this paper, initial rating system for green building is proposed to fit sustainable environment. This rating system is called **ECO-DEA Green Building Rating System (EDGRS).** The EDGRS would be integrated in a framework that is dedicated for selecting optimum sustainable building materials that was developed, expanding the features of BIM technology.

The framework utilizes Data Envelop Analysis (DEA) optimization technique and Life Cycle Cost (LCC) analysis in order to perform its designated functions as demonstrated in figure.
Although the importance of eco-efficiency as a sustainability assessment tool has significantly increased worldwide, there are few studies that adopted this concept in the construction domain Li, Hui, Leung, Li, & Xu (2010) developed a methodology for eco-efficiency evaluation for residential development at the city level, in which they linked the economic value and environmental effects together. They proposed a methodology that selects the ecological footprint as an aggregate environmental indicator to represent all resources consumed and all wastes produced by residential development. On the other hand, Saling (2002) developed a specialized form of an eco-efficiency analysis tool that focuses on quantifying the environmental effects of a product on the basis of six categories, such as raw materials and energy consumption, land use, air, water and solid emissions, potential toxicity, and potential risks. Economic data was also gathered, including all costs undertaken in manufacturing or the use phase of the product. The aim of their tool was to compare similar products and processes to simultaneously improve environmental and economic performance. They derived the overall eco-efficiency score on the basis of normalizing respective categories and applying an overall weighting scheme. In another study, utilizing BASF method, Takamura, Lok, & Wittlinger (2010)

compared the eco-efficiency of three preventive maintenance technologies of existing roadways: traditional hot-mix overlay, polymer modified hot-mix overlay, and cold mix micro surfacing. In this study, LCA and LCC will be utilized as the denominator and numerator for an eco-efficiency ratio in this study.

Eco-efficiency ratio = LCC/LCA

The approach of utilizing LCC to represent the economic value added was adopted in several research studies (de Haes, et al., 2004). The primary advantage in utilizing LCC is to be able to account for all costs associated with the life cycle environmental effects.
The objective of the study is to develop framework for green building sustainable rating system (GRS) integrating BIM technology that is dedicated for selecting sustainable green material selection. The framework utilizes ECO-DEA optimization approach and life cycle cost analysis for a sustainable façade material in order to perform its designated functions.
The scope of the research is limited to the new commercial buildings constructed in India. The objective of this paper is to develop an analytical tool that can be used to assess the eco- efficiency of building facade materials. This tool is used to evaluate the materials using data envelopment analysis (DEA), a linear programming-based mathematical approach.

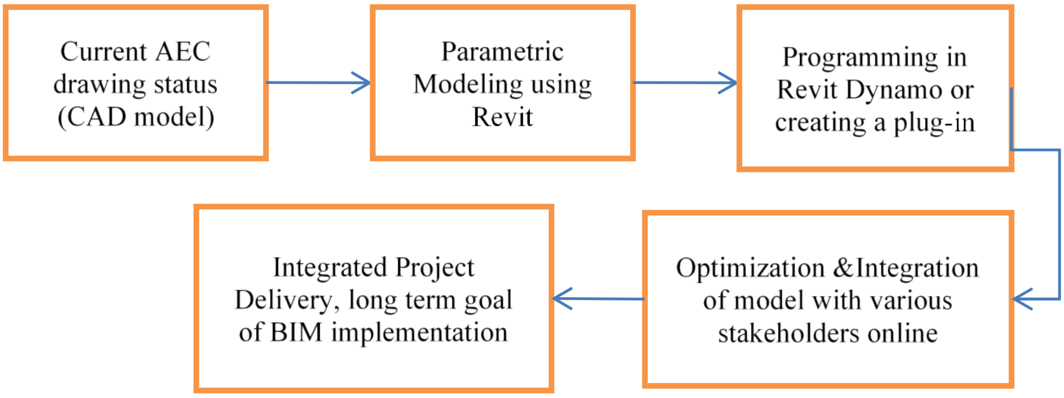

Figure 1 Proposed objective of the study

2 Objective and Scope of Work

The objective of the study is to develop framework for green building sustainable rating system (GRS) integrating BIM technology that is dedicated for selecting sustainable green material selection. The framework utilizes ECO-DEA optimization approach and life cycle cost analysis for a sustainable façade material in order to perform its designated functions. The scope of the research is limited to the new commercial buildings constructed in India.
A two-step methodology was adopted for the research:

1 First stage to develop a BIM model for an existing green building to establish a relation between BIM and IGBC rating process.
2 Second stage to develop and Eco-DEA mathematical model approach for optimizations and selection of sustainable material criteria for building façade material
3 To create and Integrated conceptual framework for assessment of green building material selection process (BIM-Model) and sustainable material optimization and selection criteria (ECO-DEA)

The green sustainable rating system (AHGRS) would be integrated in a framework that is dedicated for selecting optimum sustainable building materials that was developed, expanding the features of BIM technology. The framework utilizes ECO-DEA optimization technique and Life Cycle Cost (LCC) analysis in order to perform its designated functions.

2.1 First Stage Approach

Autodesk Revit 2020 has been used as a BIM modelling software and Dynamo for analysis. The major reason to use Revit and Dynamo is that majority of AEC professionals in India use Revit for creating BIM models.

Dynamo is graphical programming tool for design and BIM. It helps the AEC professionals to write the algorithm to enhance a design by giving more functionality to Revit that would otherwise be limited due to the nature of the software. Instead of typing out lines of code, your algorithm is composed of a series of what Dynamo calls nodes. The set of problems that Dynamo is most often used to solve are analysing BIM data, automating tedious and repetitive documentation tasks, and exchanging information between software formats. There are many advantages of using Dynamo such as user can reuse graphs from project to project, run the same process on multiple inputs, work with greater precision. Moreover, it has interpolability between different software formats.

2.2 Dynamo Plug-in

The scripting is done for a BIM model to demonstrate the practical approach. Scripting is done in dynamo to extract the information from BIM model to MS Excel for evaluating the green building score as per IGBC. A dynamo script is prepared for the evaluation of five parameters of the green building as per IGBC. These parameters are Reuse of salvaged material, Materials with recycled content, Local material, Wood based material and Green Pro certified materials.
Following Shared Parameters are created in the model:

- Distance from source (in km): This parameter takes a number input which specifies the distance of the materials of the element from manufacturing site to the project site. If the manufacturing of all materials is done within the range of 400 km, take the distance from where the maximum materials are manufactured or take the average of the distances where different materials are manufactured.
- FSC certified wood: This parameter is applied to all new wood-based products. For this calculation, the total cost of all new wood-based material should be more than 50%. This parameter takes a text as an input (Y for yes and N for no).
- Green Pro: This parameter is applied to the elements certified by CII under Green Product Certification Product (Green Pro). This parameter takes a text as an input (Y for yes and N for no).
- Recycled contents used: This parameter states whether the element has recycled content or not. This parameter takes a text as an input (Y for yes and N for no). According to this parameter at least 10% of the material cost should have recycled contents in the building to achieve the credit.
- Salvaged Materials used: This parameter is used to determine whether the element has used salvaged material. This parameter takes a text as an input (Y for yes and N for no). According to this parameter at least 2.5% of the material cost should have recycled contents in the building to achieve the credit.

The key to solving problems computationally is figuring out how to take the problem and break it down into a series of mini problems that are easier to accomplish with just a few Dynamo nodes each.

Figure 2 shows the roadmap created to extract and analyze the data from BIM model.

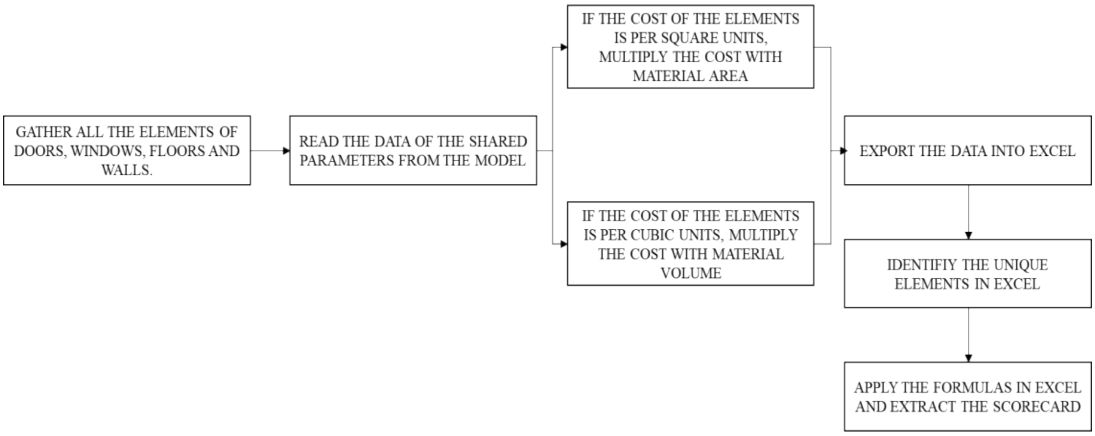

Figure 2 Roadmap for development of Plug-in

2.3 Second Stage Approach

2.3.1 Eco-Efficiency

Eco-efficiency emerged as a management philosophy by the World Business Council for Sustainable Development (WBCSD) in 1993, following the 1992 Rio Summit (Saling, et al., 2002). In the Summit, eco- efficiency was defined as “the delivery of the competitively priced goods and services that satisfy human needs and enhance the quality of life while progressively reducing ecological effects and resources intensity throughout product life cycles to a level appropriate with the estimated capacity of the Earth” (Kibert, 2013). Consistent with the aforementioned WBCSD definition, the eco-efficiency ratio consists of two independent variables: an economic variable measuring the value of products or services added, and an environmental variable measuring their added environmental effects. The eco-efficiency ratio expresses how efficient the economic activity is with regard to nature’s goods and services. According to the definition, eco-efficiency is measured as the ratio between the added value of what has been produced (e.g., income, high quality goods and services, jobs, and gross domestic product (GDP) and the added environmental effects of the product or service (Zhou, et al., 2008). Eco-efficiency improvement can be accomplished by reducing the environmental effect added while increasing the economic value added for products or services during their life cycle. Although the importance of eco-efficiency as a sustainability assessment tool has significantly increased worldwide, there are few studies that adopted this concept in the construction domain. Li, Hui, Leung, Li, & Xu (2010) developed a methodology for eco-efficiency evaluation for residential development at the city level, in which they linked the economic value and environmental effects together. On the other hand, Saling (2002) developed a specialized form of an eco-efficiency analysis tool that focuses on quantifying the environmental effects of a product on the basis of six categories, such as raw materials and energy consumption, land use, air, water and solid emissions, potential toxicity, and potential risks. Economic data was also gathered, including all costs undertaken in manufacturing or the use phase of the product. They derived the overall eco-efficiency score on the basis of normalizing respective categories and applying an overall weighting scheme. The approach of utilizing LCC to represent the economic value added was adopted in several research studies (Saling, et al., 2002, de Haes, et al., 2004).

2.3.2 ECO-DEA Analysis

This tool evaluates the eco- efficiency of facade material by using data envelopment analysis (DEA), a linear programming-based mathematical approach (Jyoti & Arpana, 2014). The ECODEA model framework consists of Inputs of Life Cycle Assessment (LCA) environmental categories based on TRACI (TRACI User’s guide and system Documentation1) viz. Acidification potential (ACD), Toxicity Potential (TOX), Eutrophication potential (EUT), Global warming potential (GWM), Fossil fuel depletion (FFD), Smog (SMG), Water Intake (WTI), Human health criteria (HHL), Criteria air pollutants (CAP), Ozone depletion (OZD), and the output constitutes Life Cycle Costing (LCC). As LCC is the only output, output multipliers are not needed for the model. This model does not force any weight restrictions on the environmental effects. Thus, the flexibly chosen weights for environmental effects enable to maximize the relative eco-efficiency of the decision-making units (DMU) with respect to other compared DMUs. BEES' software was utilized because of the availability of construction material data and build-in capability of presenting the results on the basis of life cycle environmental effect categories.

DEA compares eco-efficiency by analysing other sections in the data set. This is the major drawback of DEA because the eco-efficiency ratios are relative to the eco-efficiency of other materials in the data set. LCA methodology undergoes some uncertainties, it does not compare the criteria based on which the decision making depends i.e., which environmental category is more important in selection of facade material.

3 Third Stage: Integrated Framework-Implementation and Results

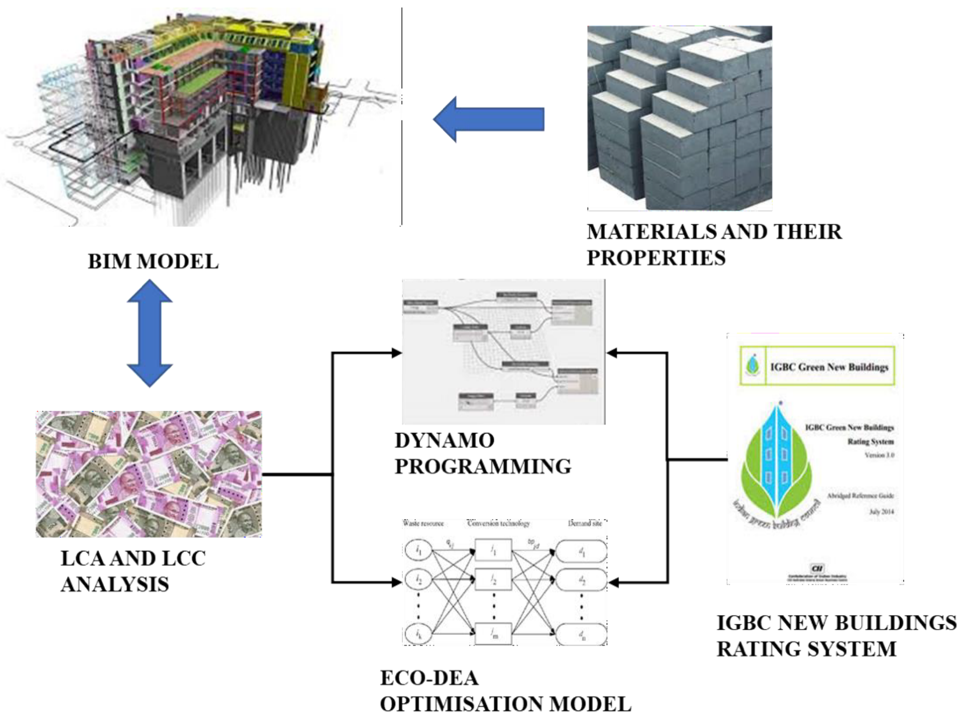

Figure 3 System Components of Integrated Framework System

The automated green building rating system plug-in for IGBC can be developed through the following three stages (as shown in Figure 3):

1) The IGBC knowledge framework is understood and deciphered into a simple format suitable for flowcharts.
2) Flowcharts are drawn as per the sequence of information required for the green building assessment.
3) Scripting is done in dynamo.

After the scripting is done in dynamo, the data is extracted from the model to MS Excel and analysed.

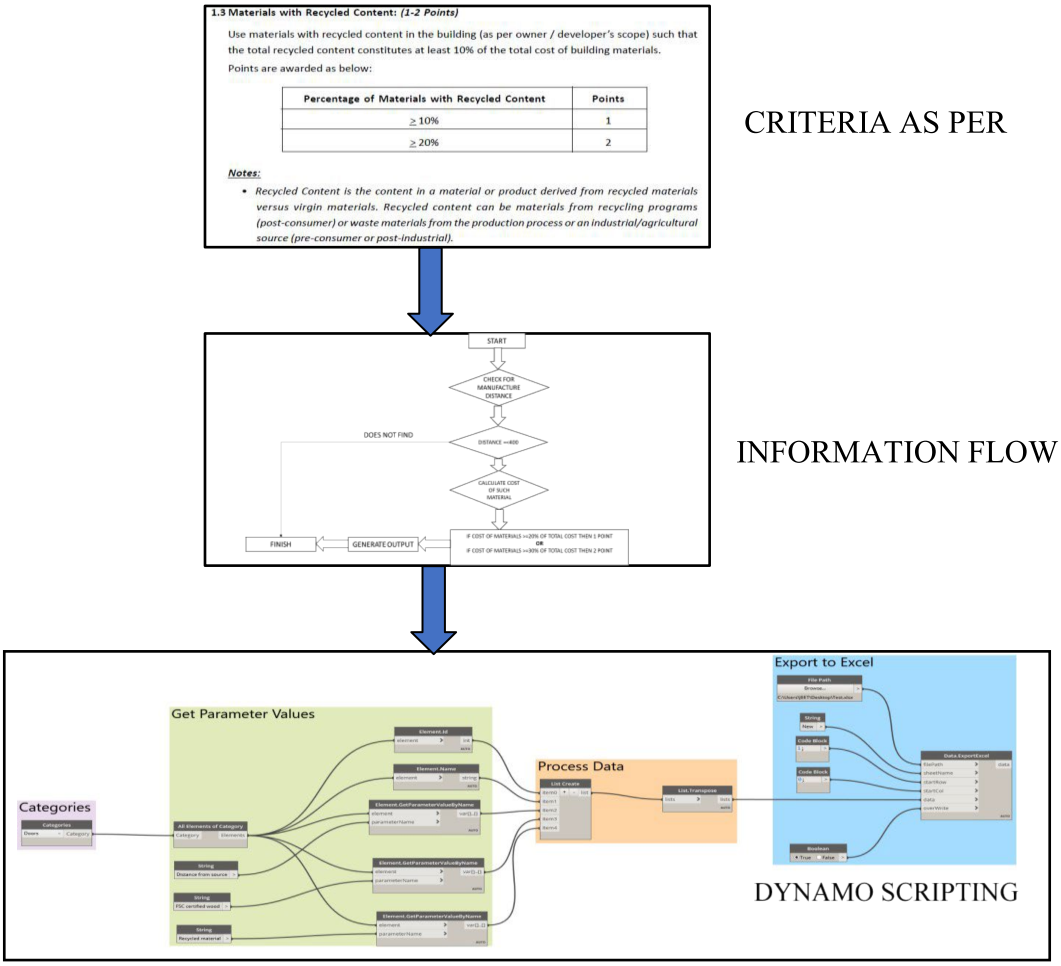

Figure 4 Stages for plug-in development

SCORECARD			
Credit	Parameter	IGBC Points Required	IGBC Points Achieved
BMR Credit 1.2	Reuse of salvaged material	2	0
BMR Credit 1.3	Materials with recycled content	2	0
BMR Credit 1.4	Local Materials	2	2
BMR Credit 1.5	Wood based material	2	1
BMR Credit 4	Use of Certified Green Building Materials, Products & Equipment	5	2
Total		13	5

Figure 5 Final IGBC Rating

4 Findings and Discussion

The calculated optimal weights (v_r) (Table 3) show which inputs were utilized for each DMU for their calculation. For instance, for DMU 1, the weights show that eco-efficiency was calculated by using only GWP, whereas other effect categories were all 0. The ECODEA results indicate that the ratios range from 2.34 to 1.17. Among wall finishes, cement plaster was found to be the most eco-efficient. The structural glazing was found to be the least eco-efficient when compared with the other exterior

wall finishes in the study.
The results showed that DEA is an effective tool to evaluate construction material alternatives and offer a critical insight to the decision maker that can lead to buildings that use much more eco- efficient materials.
In this study, a DEA-based eco-efficiency assessment framework is presented as an effective and practical way to evaluate building façade materials.

1. The developed framework utilized LCC and LCA as the numerator and denominator for calculating the eco-efficiency ratio and solved LP models to calculate eco-efficiency ratios for exterior wall finishes.
2. The ECODEA model calculated the ratios without enforcing any weight restrictions.
3. The said model predicted cement plaster to be the most eco-efficient with ECODEA ratio of 2.34. It has the least global warming potential of all the materials studied.
4. Though it has more acidification potential, toxicity but its eutrophication potential, water intake, human health and emission of criteria air pollutant is less as evident from Table 1.
5. The structural glazing is found to be least eco-efficient as per the study with ECODEA ratio of 1.17. Its acidification potential is lower (6500 mg H+ equivalents, as per Table 1) than other materials is but it has high global warming potential, smog, human health criteria and ozone depletion potential as given in Table 2.

This paper makes several contributions to construction research, including developing a mathematical model that does not require subjective weighting to assess the sustainability of construction materials and presenting a practical way to apply eco-efficiency to construction materials. The analysis of DEA results could be very helpful to decision makers to compare relative eco-efficiency of building facade materials.

ACD: Acidification Potential
GWP: Global Warming Potential
SMG: Smog
HHL: Human Health Criteria
OZD: Ozone Depletion
TOX: Toxicity potential EUT: Eutrophication potential
FFD: Fossil Fuel Depletion
WTR: Water intake
CAP: Criteria Air Pollutants

Table 1 Environmental effect categories

	Environmental effect categories									
Exterior wall finishes	ACD	TOX	EUT	GWP	FFD	SMG	WTR	HHL	CAP	OZD
1. Cement plaster (1:3)	9110	52.8	2.69	1460	9.84	733.11	1.3	138.34	2.57	0.072
2. ACP cladding	7110	19	2.79	3410	5.74	267	2.2	140	3.56	0.065
3.Exterior grade PVC panel cladding	7500	11.9	2.3	4560	6.2	322	2.5	160	2.78	0.031
4. Film coated structural glazing	6500	32	2.4	5600	3.4	600	2.1	172.5	2.35	0.055
5. Clear glass window with Aluminium Frame	6750	28	2.26	3570	3.2	523	2.6	148.9	2.5	0.036

Note: Units of measurement: ACD (mg H+ equivalents/unit), TOX (g 2, 4-dichlorophenoxy-acetic acid equivalents/unit), EUT (g nitrogen equivalents/unit), GWP (g CO2 equivalents/unit), FFD (MJ/unit), SMG (g NOx equivalents/unit), WTR (L/unit), HHL (g benzene equivalents/unit), CAP (micro disability adjusted) life years/unit), LCC (present value Rs/unit).

Table 2 Normalised Data Set

	Environmental effect categories										
Exterior wall finishes	**ACD**	**TOX**	**EUT**	**GWP**	**FFD**	**SMG**	**WTR**	**HHL**	**CAP**	**OZD**	**LCC**
1. Cement plaster (1:3)	1.23	1.84	1.08	0.39	1.73	1.50	0.61	0.91	0.93	1.39	0.28
2. ACP cladding	0.96	0.66	1.12	0.92	1.01	0.55	1.03	0.92	1.29	1.25	2.35
3. Exterior grade PVC panel cladding	1.01	0.41	0.92	1.23	1.09	0.66	1.17	1.05	1.01	0.60	1.41
4. Film coated structural glazing	0.88	1.11	0.96	1.51	0.60	1.23	0.98	1.14	0.85	1.06	0.45
5. Clear glass windows with Aluminum Frame	0.91	0.97	0.91	0.96	0.56	1.07	1.21	0.98	0.91	0.69	0.52

Table 3 Solution set

	Environmental effect categories										
Exterior wall finishes	**Ratio**	**v1**	**v2**	**v3**	**v4**	**v5**	**v6**	**v7**	**v8**	**v9**	**v10**
1. Cement plaster (1:3)	2.34	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
2. ACP cladding	1.29	0.00	0.00	0.00	1.25	0.00	1.24	0.00	0.00	0.00	0.00
3. Exterior grade PVC panel cladding	1.60	0.00	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Film coated structural glazing	1.17	0.00	0.00	0.00	0.00	0.15	0.00	0.30	0.00	0.00	0.00
5. Clear glass windows with Aluminium Frame	1.34	0.00	0.00	0.00	0.22	0.31	0.00	0.00	0.00	0.00	0.00

5 Conclusions and Further Research

BIM plays a vital role in AEC industry to facilitate the process related to construction of green buildings. With the passing time, this technology is evolving rapidly. Still, only some of the green building parameters are evaluated using software. Different parameters are evaluated using different software (e.g. eQuest for energy analysis, EcoTect for daylight analysis). The current market practice is to create a Revit model and then export the file as IFC to other evaluation software like eQuest, EcoTect, DOE2 etc. From the questionnaire analysis it was observed that Revit can be used to evaluate a lot of green building parameters. This is helpful for all the stakeholders of the construction industry as it saves a lot of time, efforts and resources.

BIM provides a platform to implement additional features for green building properties and evaluation of those properties. Visual Programming tool Dynamo can be used to evaluate the additional parameters. It allows the user to evaluate the properties of the building as per his/her requirements. In this paper, the parameters regarding building materials and resources had been added and evaluated. Although, the evaluation was done for different elements and not as different materials. In future, with complex programming and development of new nodes in dynamo, it will be possible to analyse the

materials separately and not as a whole element. So, the chances of ambiguity of rating calculation through the script will reduce. For this a complex programming needs to be developed in Dynamo.
In this study, a DEA-based eco-efficiency assessment framework is presented as an effective and practical way to evaluate building facade materials. The developed DEA framework utilized LCC and LCA as the numerator and denominator for calculating the eco-efficiency ratio and solved LP models to calculate eco-efficiency ratios for exterior wall finishes. The ECODEA model calculated the ratios without enforcing any weight restrictions. The said model predicted cement plaster to be the most eco-efficient with ECODEA ratio of 2.34. It has the least global warming potential of all the materials studied as seen in appendix. Though it has more acidification potential, toxicity but its eutrophication potential, water intake, human health and emission of criteria air pollutant is less as evident. The structural glazing is found to be least eco-efficient as per the study with ECO-DEA ratio of 1.17. Its acidification potential is lower (6500 mg H+ equivalents) than other materials is but it has high global warming potential, smog, human health criteria and ozone depletion potential. The accuracy of DEA results depends on the accuracy of the data extracted.
So, materials selected for applying the model were:

1) Cement plaster (1:3)
2) ACP cladding
3) Exterior grade PVC panel cladding
4) Structural glazing
5) Clear glass windows

Through literature review, it was established that LCC and LCA data will be required to calculate eco-efficiency ratio. LCC is calculated by finding first cost of installation from vendors in Ahmedabad and to it adding future cost of the materials. Life Cycle Impact Assessment is calculated using BEES Software. It has a huge inventory of building materials ranging from structural materials to external cladding.

In this study following assumptions regarding LCC have been made:

1) Discount rate: 8% *(Source: Reserve Bank of India)*
2) Inflation Rate = 8.31% *(Source: Ministry of Commerce and Industry, India)*
3) Total life assumed = 50 years
4) Salvage value = 0
5) Cement plaster facade has to be maintained approximately every ten years at 50% of the cost of first-time installation.
6) ACP cladding has a life of fifteen years, so every fifteenth year it is replaced.
7) PVC cladding has also a life of fifteen years and has to be replaced after that.
8) Structural glazing (clear and coated) has longer life. We have taken it as twenty years.

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Developing an early prediction model of bankruptcy in the UAE construction industry

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Abstract
The aim of this research is to develop an early prediction model of bankruptcy providing the UAE construction companies with practices to avoid the threat of insolvency and its related consequences on individuals and the economy. The methodology used to achieve the aim of the research is by collecting data from literature review contributing to develop a survey and semi-structured interview questions. The focus of the research methodology is to identify the reasons for bankruptcy, understand organizational strategies during financial crises and pandemics, rating the challenges facing the developed model, and evaluating the developed model of bankruptcy. The outcome from the survey and interviews is that the main reasons for organisations bankruptcy are due to cash flow management, payment delays, and false cost reporting which is justifying the data in the literature review. Moreover, there is no prime reason for bankruptcy as much as it is a series of poor decisions. Another finding is that the level of knowledge and awareness about bankruptcy has increased especially during the current pandemic contemporary with the evaluation of the developed prediction model that is designed specifically for the UAE construction industry. The evaluation of the developed model by participants is good for being accurate, suitable, efficient, and realistic. This research provides a framework for the companies to predict the future risk of insolvency. Moreover, assisting the researcher to investigate and improve the developed model which is lacking transparency and published data on selecting the most important criteria and variables for the model.

Keywords
bankruptcy prediction model, construction industry, UAE.

1 Introduction

The strength of any market is affected by the quality and performance of the economic and behaviour towards the current and future challenges to maintain stable and strong market economy. For instance, the global financial crisis had a crucial effect on the global businesses resulting of economic recession as in the report by (Jakóbik, 2018). The main problems affecting the business environment, performance and quality as mentions in the study by (Daniela, Mária and Lucia, 2016) are the level of consumption and debt risk which is caused by delayed or unpaid invoices. Therefore, the development of the studies of early predictions of bankruptcy in the construction industry are significantly increased. The study by (Jakóbik, 2018) mentions that the benefit of developing an early prediction model of bankruptcy will assist the companies to predict future insolvency depending on financial and performance indicators.

The aim of this research is to develop an early prediction model of bankruptcy to provide the UAE construction companies with practices to avoid the threat of insolvency and its related consequences on individuals and the economy. This will be done by identifying the causes of bankruptcy in the construction companies, reviewing the current tools, method, and criteria for successful prediction model in other industries and their applicability in the construction companies, investigating the current framework of bankruptcy prediction in the UAE market.

The methodology used to achieve the aim of the research is by collecting data from literature review contributing on developing a survey and semi-structured interview questions. The key focus in the research is to identify the reasons of bankruptcy, understand organizational strategies during financial crisis and pandemic, rating the challenges facing the developed model and evaluating the developed model of bankruptcy. The outcome from the survey and interviews is that the main reasons of bankruptcy are due to cashflow management, payment delays and false cost reporting which is justifying the data in the literature review. Another finding is that level of knowledge and awareness about bankruptcy has increased especially during the current pandemic contemporary. The evaluation of the developed model is fair for being accurate, suitable, efficient, and realistic.

2 The importance of construction industry to the economy

The construction industry is significantly considered as vital sector in developing the economy of any country. The strength of the construction industry relies on the supply chain serving the purpose and the need of building materials consumption rate such as glass, wood, tiles, etcetera which will increase the demand of manufacturing and producing more building materials. As a result, the construction industry will be improved and it will help the growth of the economy by solving the social problems of job opportunities and expanding on government projects by improving the infrastructure, utility projects and local residential/commercial projects by increasing the demand of building material variety. (Hosein and Lewis, 2005).

The importance of the construction industry is having a high contribution to the GDP with a percentage of 8 - 10 % in comparison to other industries. However, the industry is recognized for being competitive in bidding that sometimes the clients aim to award the contract to the lowest bidders, while overlooking the importance and the effect of such behaviour on the long-fragmented supply chain. The failure of one business in the construction industry supply chain can lead to failure of other businesses who relies on payments to finance their work on site.

2.1 The culture in the UAE construction industry

The UAE construction industry has its own culture and behaviour compared to other countries due to constantly updated government vision for a smart and flexible city. Also, exhibition of Expo 2020 increased the delivery of fast-track projects. For instance, (Al-Malkawi and Pillai, 2013) mentions the characteristics of the UAE construction industry being in the frontline of the news depending on oil treasure as the strength of the country. However, despite being a leading developed country the global crisis of the pandemic succeeded to cripple the UAE market. Therefore, real estate and construction industry was severely damaged causing a declining in profitability, and liquidity.

In the report by (Ayoub *et al.*, 2017) mentions that due to the global crisis in 2008 the UAE government had introduced rescue culture by forcing new bankruptcy law to the UAE market called “Liabilities of directors”. The law has introduced comprehensive procedure to be followed. The new law defined the liability for the directors and managers towards insolvency in case they commit any criminal action of hiding or damage any company records or company assets. In the report by (Mulla, 2019) mentions that there was an improvement in the UAE law towards business environment which involved amendment in bankruptcy law, anti-money laundry and certain business ownership.. In the report by (Alton, 2019) explains the procedure in a framework to avoid the future risk.

In the study by (Umar *et al.*, 2020) mentions that the majority of project delays in the UAE construction is due to a combination of negative factors such as time overrun, cost overrun, payment delays by clients, bankrupted companies, disputes, arbitration and litigations. In the study by (Alameri, Rahman and Nasaruddin, 2020) mentions that the UAE construction culture is having a diverse group nationalities, languages, ethics, religions, beliefs and cultural backgrounds. Therefore, it will require project managers to overcome the risk of any conflicts, communications, and differences by embracing and adapting the change to act positively towards project success.

3 Bankruptcy

There are several definitions of bankruptcy as in the research by (Horváthová and Mokrišová, 2018) mentions that bankruptcy occurs in several forms such as the liabilities of the companies exceeds the value of their assets, deficient use of the company resources, inability to survive the competition in the market due to failure of decision making in project bidding and management, the reduction in sales and inefficient of managing the project activities. To simplify the meaning of insolvency is that value of the company liabilities or debt is more than the value of the company assets. Thereof, at that stage the company should start searching for solutions to overcome the debts such as finding new funding resources, restructuring the company, and appointing a liquidator.

3.1 Construction bankruptcy

The complexity of construction industry involving various different stakeholders with lack of communications is placing the industry in major risks of failure as in the research by (Arain, 2008) mentions that construction industry is associated with a lot of risk and uncertainties such as the constant failure of projects delivery on time and cost, projects disputes and change of design due to lack of management and communications during design stage. Additionally, contractors are forced to take all the risks and be able to maintain short and long financing terms. For instance, the contractor will have on the short term to finance the capital cost of projects, stock and procure the materials while on the long term to maintain retained profit and equity investment. Therefore, the number of bankrupted contractors in the construction industry tremendously increased.

3.2 Reasons of bankruptcy

The contractor’s managerial role is under the influence of internal and external factors affecting decision making. Organization structure and dealing with stakeholders, competitive market and inflation can place the company in making a strategic decision that is associated with risks and uncertainties leading to insolvency. In the article by (Rice, 2013) mentions that there are many influences affecting the contractor failures in the construction industry from making wrong strategic decision such as; selecting poor projects, entering new markets and the need of increasing the volume and expansion. On the other side, from organizational decisions such as poor operation management, insufficient profit, poor performance due to the lack of experience, the lack of leadership skills and poor contract practices.

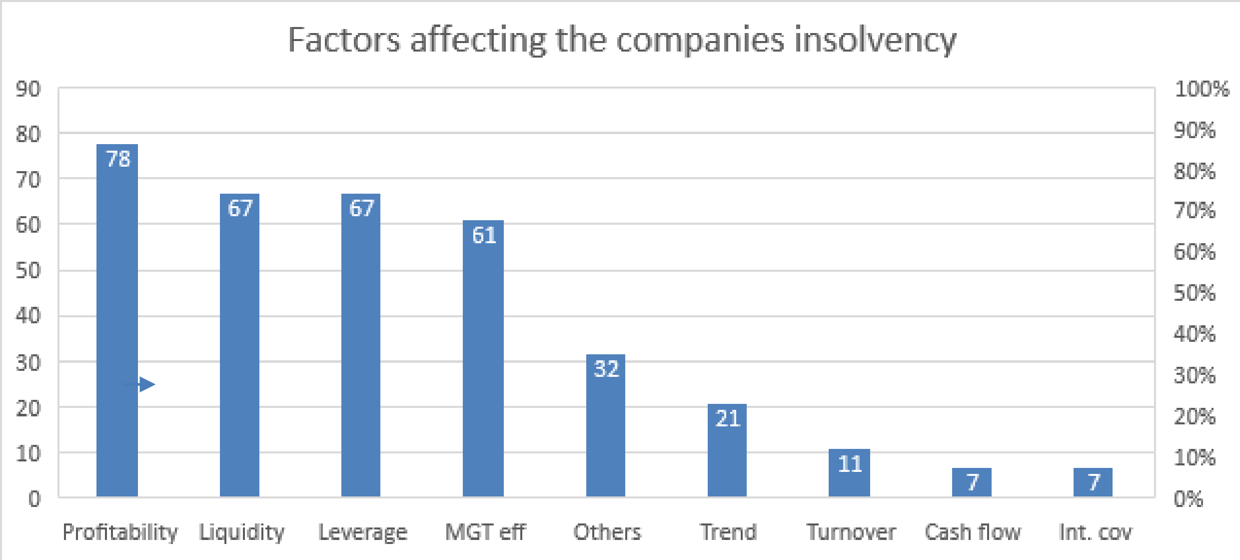

Figure 1. The most common factors affecting the company's insolvency

4 Bankruptcy prediction models

4.1 Development of bankruptcy prediction models

Bankruptcy prediction models have been developed over the years as by (Kuběnka, 2016) explores the progress development of bankruptcy prediction models. In the early beginning of the 20th century the importance of bankruptcy prediction has been increased. The initial approach distinguished comparison between companies' insolvency status depending on single indicators or financial parameters. However, the revolution of bankruptcy prediction models appeared by Altman in 1968. He developed a measurement method of bankruptcy by Z-scoring through simulation of different indicator impacts on the financial situation of companies. Later, Altman developed the most popular technique called 'Multivariate Linear Discriminant Analysis' to forecast companies' bankruptcy.

4.2 Bankruptcy prediction in construction

The culture of the construction industry associated with different type of stakeholders, decision making, type of organization structure and long fragmented supply chain that depends on regular payments. Financing system and investment in the construction industry is completely different from other industries. Therefore, the tools and criteria to be applied in other industries will not be effectively applicable for margining and evaluating the financial risk in the construction industry as in the report by (Sun, Liao and Li, 2013). Moreover, the study by (Kuběnka, 2016) and (Spicka, 2013) states that what appears to be failure of companies in the construction industry is related to shortage of cash especially in the short term, and low rate of labour productivity.

5 Creating a bankruptcy model for the UAE industry

The first step in the proposed bankruptcy prediction model will be based on large data analytic that will consist of collecting financial data of UAE construction companies. Then, to be converted to key value pair structure and presented in the process of big data analytic database "Apache Mahout with LML" and "HBase" as per (Hafiz *et al.*, 2015) study refer to figure no.2. However, (Saeed *et al.*, 2020) mentions that UAE construction industry disadvantage lack of published data, low transparency in financial information, unknown average market earn value, volume of the total market share and limited historical shared data by the companies in the construction industry.

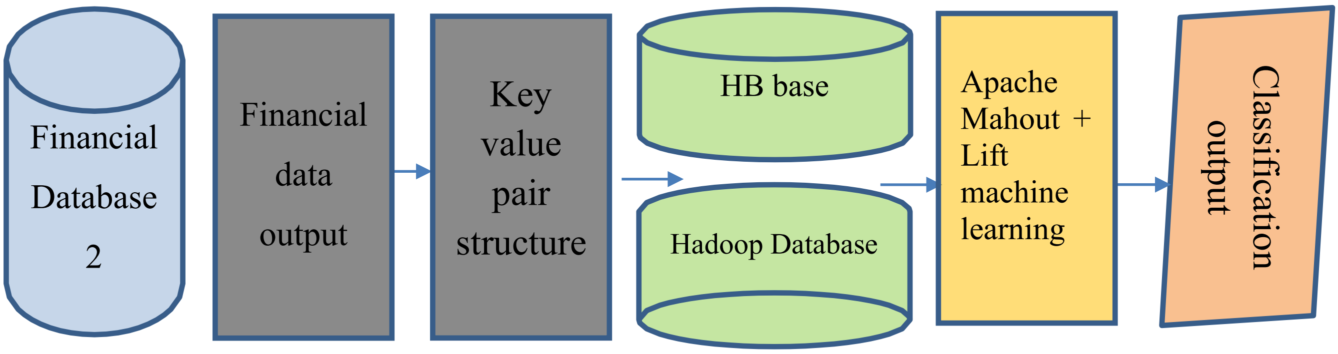

Figure 2. The flowchart of the big data analytic.

5.1 Criteria for creating a bankruptcy model

The research by (Karas and Reznakova, 2017) significantly explains that when deciding on creating a prediction model to distinguish the purpose of that prediction model for more successful prediction model. According to (Alaka et al., 2018) which used systemic review of previous studies to create a framework for companies to follow where they must achieve accuracy of bankruptcy prediction models by using suitable mechanism and serve the purpose of each company.

- **Accuracy:** Prediction classification with minimum error, Type I and II.
- **Result transparency:** Tools should be interpretable.
- **Sample size:** The approximate sample size suitable to tools and function optimally.
- **Variable selection:** Variable selection method required for optimum results.
- **Updatability:** Tools should be easy to update in case of any dynamic changes.

5.2 Selecting variables when creating the model

(du Jardin, 2009) divides variable that reflects a company's failure into three categories and it can be a result of one or more category. The first category focuses on financial documents (balance sheet and profit/loss account) and characteristic behaviour (strategy, management, and organization structure). The second category is a reflection on company business environment during lifetime (interest rate and growth). The third category is related to market evaluation of financial risks and status of the companies in the market. Also adding that researchers when developing a bankruptcy model tend to use two step methods to select the suitable and accurate variables in their model.

5.3 Model design

The design of LSTM RNN is consisting of input layers of selected variables suitable in the UAE market on the basis of time: current year time (t) previous years (t-n), hidden layers, a "SOFTMAX" layer and output layer as in the study by (Jang, Jeong and Cho, 2020) refer to Figure 3.

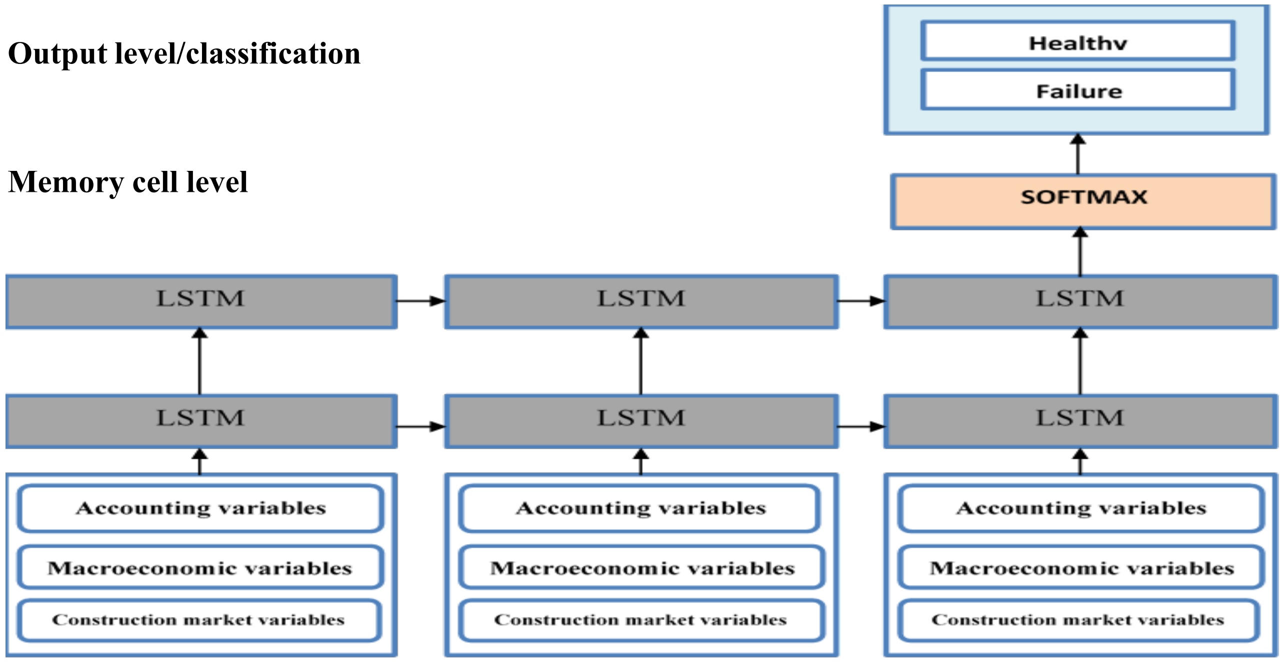

Figure 3. The developed flowchart for the prediction model of bankruptcy.

6 Research Methodology

The primary data was collected by a comprehensive review of vital role of the construction industry to the growth of the economy. Identifying most common reasons behind bankruptcy in the UAE construction industry. The selection of important criteria and variables when creating the bankruptcy prediction model based on each company visions, strategy, and requirements. Developing an early prediction model of bankruptcy based on the current research and the UAE market. The secondary data was recorded from articles, journal, conference papers and books.

Predefined set of closed-ended questions are prepared to collect information from various players in the UAE construction industry such as client, consultant, contractor, sub-contractor, and finance managers to achieve the objectives and aims through a critical quantitative analysis. The survey was designed in a way to measure suitable perdition models of bankruptcy.

Semi-structured interviews that include specific topics which are prepared in advance to collect the information from the interview. It will be sent to professionals and experts in the construction industry such as client, consultant, contractor, sub-contractor, and finance managers. The interviews were conducted online due to the current situation of covid-19 and its restrictions.

7 Findings and Discussion

7.1 The importance of the construction for economy growth

Most of the responded agreed with the study by (Miroshnikova and Taskaeva, 2018), (Omopariola *et al.*, 2019b) and (Durdyev, Omarov and Ismail, 2016) that the construction industry is highly important to the supply chain and considered as essential industry and resemble the main strength and economy growth of any country. All the interviewees expressed that family businesses and privately owned companies have the strength of diversity contribution to stability to the industry. All the interviewees agreed on the important role of stable companies for economic growth due to the demand of building materials as in the study by (Tse and Ganesan, 1997).

7.2 The main resaons of bankruptcy in the UAE

The majority responded that the main reason of bankruptcy in UAE construction industry is due to payment delays from clients affecting the supply chain and survival of the companies as in the study by (Mahamid, 2012). Most of the participants were from main contractor/subcontractor side that responded with familiar and fair knowledge on bankruptcy which impacted greatly on the findings and outcome of the survey which means there is high awareness of bankruptcy in the UAE construction industry. Also, means most of the failure happens on the lower level of the supply chain due to cash flow and payments delays from client's side.

Furthermore, force majeure such as financial crisis and global pandemic is having a huge impact on the stability of the market as in the study by (Kerr M., Ryburn D., 2013). Adding to this company procedures and strategies with bank loans interest rates, organization structure and culture is the third reason of bankruptcy. The outcome was good practice from client's side to mitigate risk and cash flow management however they ignored quality and risk of variations.

7.3 The current strategies to mitigate the risk of bankruptcy in the market

All the interviewees are having their own procedures and strategies when it to comes to mitigating the risk and maintaining a good cash flow. Moreover, they are adapting good contract practices in terms of applying back-to-back payments and focusing on cash collection. The interviewed organizations are cautiously keen on selecting clients with a good reputation in the market. However, the main reason of bankruptcy are payment delays and no payments at all.

7.4 The most important criteria when creating the bankruptcy model in the UAE

Most of respondents preferred that the model should be updated, flexible and specified in comparison to other criteria as in the study by (Alaka *et al.*, 2018). Most of respondents preferred that the model should consider current ratio variable which is (current assets/current liabilities) with 68 responding in comparison to other variables as agreed in the study by (Wang and Lee, 2008) and (Edum-Fotwe, Price and Thorpe, 1996) about the importance of the financial variables as indicators.

7.5 The role of implementing the bankruptcy model within the organization

The majority agreed that on a strategic level shareholder should import the developed model. Also, the implementation role to be assigned to general managers, power of authority remains between board members, shareholders, general managers, and directors. The responsibility relies between directors, project managers and account department. The role of monitoring will be assigned to accounting department, the role of practicing to be assigned to quantity surveyor and correction action to be with commercial managers. The majority responded that shareholders are the most to benefit in comparison to others with a total 69 responses.

7.6 The outcome from the developed model

The respondents stressed on increasing the awareness and importance of bankruptcy prediction models as in the study by (Al-Malkawi and Pillai, 2013). The majority agreed that developed model would be accurate, suitable, effective and realistic with 69 equal responds as in the study by (Sun, Liao and Li, 2013) and (Jang, Jeong and Cho, 2020). The outcome is very good to begin considering the development and implementation of such model within organizations to overcome the future risk of insolvency and maintaining a strong position in the UAE construction industry as in the study by (Karas and Režňáková, 2017).

7.7 The role of the UAE government towards stable market

The feedback received from the interviewees advocates the importance of the governmental role, law, and regulation to control payment delays from client side to support the flow of cash to the supply chain and maintain stability and solvency within the industry. The UAE government should monitor and implement new payment mechanisms to support main contractors and the supply chain in the construction industry. A notable important result was the critical the role of the government to support the companies for a stable economy.

8 Conclusions and Further Research

The outcome from literature review on exploring reasons behind bankruptcy was that there are different reasons of bankruptcy depending on which can be categorized into three groups related to economic conditions such as; liquidation, competitive market and inflation. Project management such as; organization structure, market entrants, poor operation managements, poor performance and poor contract practices. Financial position such as; insufficient profit, cashflow management, payment delays and no payments. Moreover, the outcome from the survey and the interviewees was that the main reasons of bankruptcy in the UAE construction industry is due to cash flow managements, payment delays, no payments from clients and false cost reporting.

The prediction models of bankruptcy should be specifically designed for the construction industry and the requirements of each organization. However, the interviewed organizations do not find that prediction models of bankruptcy viable since they adapt their own strategies and procedure. Moreover, when it comes to liquidation, profitability and cashflow management, they have strategic teams to act and produce alternative plans by being selective with their clients using available information of client background and reputations. When creating the model, there are specific criteria depending on the vision of each organization and their strategies.

The main concept of the model is to classify the financial position of the organizations based on an input layer of variables (construction, financial, macroeconomic) using processing layers and output layer with classification and results. The model designed on storing big data and selecting the required criteria and variables depending on each organization choice. Based on rating the developed prediction model and vision by storing the organizations previous data. The rating of the developed model is very good as it is accurate, suitable, effective, and realistic. Moreover, the participants encouraging on adapting future strategies to avoid bankruptcy.

The recommendation is the importance role of the UAE government to monitor organizations performance in the adapted framework. Adding to that, implementing new payment mechanisms to support the supply chain with attention to new market entrants and poor organizational culture. Moreover, construction culture adapted in the UAE needs to be improved by implementing new contract form replacing FIDIC that associated with conflict, disputes and not being collaborative.

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An Investigation of the Influence of Public Clients on Contractors' Behaviour towards the Modern Methods of Construction

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Recently, the Modern Methods of Construction (MMC) are gaining ground due to the support of both the private and governmental sectors. However, the scale of the uptake among more traditional contractors is still weak. On the other hand, public clients have a track record in motivating the traditional sector to adopt innovation towards meeting their specific needs. This paper aims to investigate the gaps within the public sector and their ability to accelerate innovation. The study will review existing literature relevant to understand the required relation and influence. The central hypothesis of this research is that public client's engagement in procuring MMC projects would trigger and accelerate traditional contractors' organizational transformation to adopt such methods. Hence, this study aims to understand the complex dynamics of the involvement of public clients on possibly motivating traditional contractors towards offering innovative solutions. The findings of this research would support the effective intervention for more effective diffusion of MMC and add to the knowledge of facilitating a greater adoption of innovation within the UK public bodies. The main objectives of this research are to a) Understand the relation between public clients and contractors, b) Examine the influence exerted by public clients on contractors' behaviour, and c) Investigate the ability of public procurement frameworks to act as integrators towards increasing the adoption of innovation. The findings highlight a gap within existing literature represented by the limited studies addressing contractors' behaviour in the public client context, particularly in MMC, and more understanding of public clients' decision making processes are needed to enable researchers and practitioners to have better understanding on contracts' behaviour towards the adoption of innovation's body of research.

Keywords: Modern Methods of Construction; Accelerating Innovation; Public Clients; Adoption of Innovation; Public Procurement Frameworks

Introduction

The construction industry is under extreme pressure to meet market needs whilst ensuring vast developments through embracing technological advancements, abiding by sustainability guidelines, and significantly reducing associated risks. Such a pressure has created a new direction within the industry, towards methods that would enable the industry to address such challenges. The Modern Methods of Construction (MMC) are methods that transforms major construction activities from being executed in an uncontrolled, risky, and costly environment, to a more certain one. However, despite their proven benefits, such methods are yet far from reaching their full acknowledgement from the industry, where most activities remain largely leaning towards traditional ways of delivering construction projects (KPMG, 2016).

Public clients have a potential to exert an influence on the construction sector to adopt innovation. Such a characteristic, in the context of MMC, might be beneficial in driving the industry for a fundamental transformation. To achieve a better understanding of such key stakeholders, their importance, behaviour, influence, and decision-making processes are to be investigated in line with the adoption of innovation studies. This study aims to highlight the gaps within existing research literature to enable research to focus on the pressure points that can enhance the adoption of MMC. This study adopts a systematic literature review that critically examines collected studies to further understand the dynamics of public clients' decisions and their ability to embrace change. The relationship between public clients and the contractors and the influence exerted by the client on its supply chain's behaviour are to be critically analysed.

Public Clients can be defined as organizations that uses government and social funds to ensure non-profit approaches within their procurement for better value (Hartmann et al., 2015). Those clients play vital roles in the construction industry, shaping construction processes and future directions. In terms of change, public clients are vital in triggering change and innovation as one of their characteristics. However, public clients must initially accept change prior to imposing an effective influence on other stakeholders to take similar steps (Manley, 2006). Such acceptance is of importance due to their negative potential in acting as innovation inhibitors as acknowledged by (Ivory, 2005). The same study reports the need is not to require public clients to merely focus on time, cost, and risks only; but also create an avenue for innovation as an equal addition to the standard concerns.

As an emerging innovation, the Modern Methods of Construction (MMC) are currently being featured by the UK government due to their potential in addressing the key industry needs in terms of sufficient supply, certainty increase, and sustainability perspectives. As an innovation, MMC is taking interest in the construction industry’s public body, alerting for a potential positive transformation. Yet, the intake of MMC among the key stakeholders is still unsatisfactory, with only £1.5 billion being as an input to all practices categorized as “not routinely” done in the UK industry (UKCES, 2013). In the context of client’s influence, Winch (1998) suggests that clients can pressure the industry to accept, generate, and implement innovation, but only if the clients were keen to accept such approaches. Aligning this with the public body, the government recently published “The Construction Playbook”, which emphasized the need to strictly abide by 14 policies as an approach to ensure that emerging and innovative practices are being considered within public procurement practices (Cabinet Office, 2020). The document emphasized the use of MMC among public clients and identified the roadmap for clients to accept such approaches in their construction options.

Coherently, Nam & Tatum (2010) argued that it is not the clients’ motivation and willingness that can embrace acceptance and change, but the awareness and technical knowledge and experience are key for the effective thrive of innovation. Similarly, Koch & Hauknes (2002) discussed that procurement of innovation cannot be formulated in isolation and there is a need for an “interaction” among the key stakeholders through proper behaviour that can drive the industrial dynamics towards meeting the desired goals. This implies that both parties, representing supply as contractors, and demand as public clients, have a vital role in achieving the required transformation. Previously, research indicated that public clients were usually ignored alongside their role in potentially driving innovation and change across the region (Lindblad & Gustavsson, 2021). Hence, there is a need to understand the relation between the public client and the contractor and how is the latter is being influenced to adopt innovation by the former.

Methodology

This study focuses on reviewing existing literature towards identifying potential gaps within previously published works; Subsequently, enabling a better understanding of the unanswered questions that future studies can cover and address. Towards both defining and refining those questions, reviewing literature is the initial vital step in any research process (Carnwell & Daly, 2001). This study adopts a narrative literature review, relating existing studies to emerging innovations, an approach that acts as a credible method in consolidating research works relevant to a specific topic (Chow et al., 2005). Due to the limited research on public clients and their abilities to enable innovation, this study identified 10 articles, distributed as seven from journal papers and three from international conference proceedings. The journals were stated as publishing scholarly studies and are listed in the top construction management journal rankings by Wing (1997) such as Construction Management and Economics (CME) and Journal of Management in Engineering (JME). Moreover, frequently cited studies are included as well in this research, represented by Structure and Infrastructure Engineering, Facilities, and Engineering Sustainability Journals. Studies collected are represented in the below table.

Table 1: Studies and Resources

Resource	Title	Journal/Conference
(Lingard et al., 2019)	The client's role in promoting work health and safety in construction projects: balancing contracts and relationships to effect change	Construction Management and Economics
(Gurevich & Sacks, 2020)	Longitudinal Study of BIM Adoption by Public Construction Clients	Journal of Management in Engineering
(Lindblad & Guerrero, 2020)	Client's role in promoting BIM implementation and innovation in construction	Construction Management and Economics
(Lingard et al., 2019)	Embedding occupational health and safety in the procurement and management of infrastructure projects: institutional logics at play in the context of new public management	Construction Management and Economics
(Kadefors et al., 2019)	Public procurement for carbon reduction in infrastructure projects – an international overview	Sustainable Built Environment Conference 2019 (Sbe19 Graz) Conf. Series: Earth and Environmental Science

(Rosander & Kadefors, 2019)	From project to policy: Implementing a collaborative procurement strategy in a public client organization	Proceedings of the 35th Annual ARCOM Conference, 2-4 September 2019, Leeds, UK, Association of Researchers in Construction Management
(Lam & Gale, 2014)	Framework procurement for highways maintenance in the UK: can it offer value for money for public-sector clients?	Structure and Infrastructure Engineering
(Alharthi et al., 2015)	The changing role of the public client in construction procurement	Proceedings 30th Annual ARCOM Conference, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management
(Love et al., 2012)	Procurement of public sector facilities	Facilities
(Sourani & Sohail, 2019)	Barriers to addressing sustainable construction in public procurement strategies	Engineering Sustainability

Discussion

Importance of Public Clients

Public clients are referred to as key stakeholders who can influence the whole industry. As decision makers, public clients acquired their reputation to influence construction supply chains (Gurevich & Sacks, 2020). Having such an influence, public client organizations tend to be directly responsible to promoting innovation across the industry (Lindblad & Guerrero, 2020). This is achieved by supporting the innovative environment through the power that public clients can exert to achieve more efficient processes. Moreover, Lingard et al. (2019) report a case where public clients have driven an innovation that was effective to the overall sector, this can be justified by the scale of such clients in the overall industry's turnover, representing around 40% (Sourani & Sohail, 2019). Such a staggering percentage is distributed in vast construction activities that includes education, social services, libraries, and transportation (Lam & Gale, 2014). However, Sourani & Sohail (2019) reports that different barriers exist and can influence public client's decisions to include innovative practices in their procurement strategies.

Public Client Behaviour

Public client's behaviour is a vital aspect to be investigated to highlight the dynamics of their procurement activities. It is reported that a gap in research exists with respect to the clients' role and behaviour which in return is halting more coherence of their capabilities (Alharthi et al., 2015). Lingard et al. (2019) report that clients' activities are influenced by their beliefs, values, and assumptions that in return can impact embracing change or accepting innovation. Moreover, another key factor influencing clients' decision and behaviour are the emerging policies that regulates the public body's strategies (Rosander & Kadefors, 2019). However, these policies and governmental trends are not always effectively influencing public clients as required. Coherently, Sourani & Sohail (2019) indicated that UK public clients have been reluctant to align with many governmental publications, which aimed to facilitate innovation, due to the existence of several inhibitors. Such functions influencing clients' decisions can be linked as "excuses" for clients not accepting innovation practices. On the other hand, Lindblad & Guerrero (2020) suggest that clients can adopt "innovation policies" that exploit the competitiveness of the industry and result in client's behaviour to influence contractors. The same was reported by (Lingard et al. (2019), as the increase of competitiveness triggered by the client's demand increases the price competition that in return enhances the procurement decisions. In the UK case, Kadefors et al. (2019) reports that the leadership characteristics in clients can strongly influence behaviours in the contracting business.

Contractor-Client Relationship

Understanding the relationship between both the supply and demand can result in further understanding on the avenues to integrate innovation. Gurevich & Sacks (2020) highlight that ensuring a long-term relationship, that public clients can govern, was proven to produce values that are manifested in the key project activities, enabling successful outcomes towards project completion. Similarly, collaboration was described as a vital aspect strengthening the relationship and ensuring more efficiency and less uncertainty (Rosander & Kadefors, 2019). Arguably, Lingard et al. (2019) discussed that this relationship is easily hindered and client interventions, if not being carefully managed, can lead to impacts on the contractor-client relationship. Similarly, Lingard et al. (2019) reports that clients must not be involved in activities that might result in damages on the vital relationship with the contractor, and rather must focus on the activities that improve innovative practices. As the relationship is very fragile, Lingard et al. (2019) also discussed that the development of “mistrust” from the supply side can have negative effects on the overall collaboration desired.

Clients Influencing Contractors

The influence of clients on contractors as reported by existing literature can enhance the understanding of the requirements needed to enhance innovation. Traditionally, clients adopted “control mechanisms” in an attempt to ensure that contractors are adhering to proper performance measures throughout their projects (Lingard et al., 2019). This control was merely implemented as one of the clients’ main objectives. Lindblad & Guerrero (2020) reports that clients can promote interaction in their projects, triggering competition between the contractors to drive innovation and succeed in creating a competitive environment. This in return was indicated to be an effective strategy that influenced contractors to embrace change. Similarly, Sourani & Sohail (2019) reports that this change cannot be embraced within the traditional sector due to their “passive culture”, unless this was firmly initiated by the client. Such an influence is extended to the use of public procurement frameworks, where promising relations for long-term collaboration, is influencing contractors to improve as an approach to stay within the loop of future works and business opportunities (Lam & Gale, 2014).

Knowledge and Awareness

Knowledge and awareness of were emerging themes within existing literature being referred to as vital prerequisites. Acquiring sufficient knowledge is key for any organization and is accompanied by deeper value and better future judgements (Gurevich & Sacks, 2020). Kadefors et al. (2019) reports that such knowledge plays a vital role in sustaining “long-term innovation processes” that is merely done through exchanging such knowledge between projects. On the other hand, not acquiring knowledge can act as a significant inhibitor in the decision-making process where client lack sufficient means to make an effective decision (Rosander & Kadefors, 2019). Coherently, Alharthi et al. (2015) indicates that there is evidence of the sector’s behaviour in not learning from previous projects, where this is halting the improvement within procurement strategies, and suggests that “regular review” is required to continuously develop and acquire knowledge. In the public sector, innovations must be considered early and in the design stages to ensure an effective outcome (Love et al., 2012). Where Sourani & Sohail (2019) report that the lack of awareness within the public body on specific innovations will either result in ignoring those or implementing the minimum adoption just to comply with existing regulations. The same study suggests that education institutions must partner with public clients to further ensure that the knowledge and awareness exist among the decision makers.

Adoption of Innovation

To adopt innovation is a critical aspect that require more research on the dynamics of how such an adoption is being met within public bodies. Gurevich & Sacks (2020) indicates that to reach an effective adoption, levels of coordination and motivation are expected through public agencies to formulate suitable strategies capable to create the right conditions. Due to the construction industry's bad reputation of minimum productivity, lagging other industries, public policies could enable the adoption of innovation to address such a lag (Lindblad & Guerrero, 2020). The same study reports that innovation is a "linear process" being offered by providers and attracted by clients to meet ongoing needs, and this can be perceived as the dynamics on which the market must understand in order to achieve more adoption of innovation within the public construction sector. On the other hand, contractors can play a vital role as well, if permitted, to increase such integral adoption. Love et al. (2012) reports that the inputs of contractors in the design phase is a vital action that stimulates innovation. However, Sourani & Sohail (2019) reports that due to the public sector's nature, public clients can easily ignore adopting innovation if the time factor wasn't for their advantage; for instance, meeting a limited funding opportunity.

Procurement Frameworks as Integrators

Public procurement frameworks can play an integral role in facilitating the adoption of innovation. Lindblad & Guerrero (2020) defined the integrating role as the action that brings two innovation actors together through specific practices. Being developed in the UK and in line with the European Parliament for coordination, such agreements aims to ensure long-term relationships between public clients and contractors (Lam & Gale, 2014). However, it is reported that despite the effectiveness of such frameworks, those are not yet currently being accepted by all the key construction stakeholders. In terms of innovation, change towards innovation is discussed to be complex between the supply and demand sides in the public sector (Kadefors et al., 2019). This required frameworks that can drive such change and embrace acceptance between both sides. The government is aiming to enhance construction through such frameworks (Lam & Gale, 2014), where those can be described as the integrators with the potential to increase the adoption of innovation.

Theoretical Framework

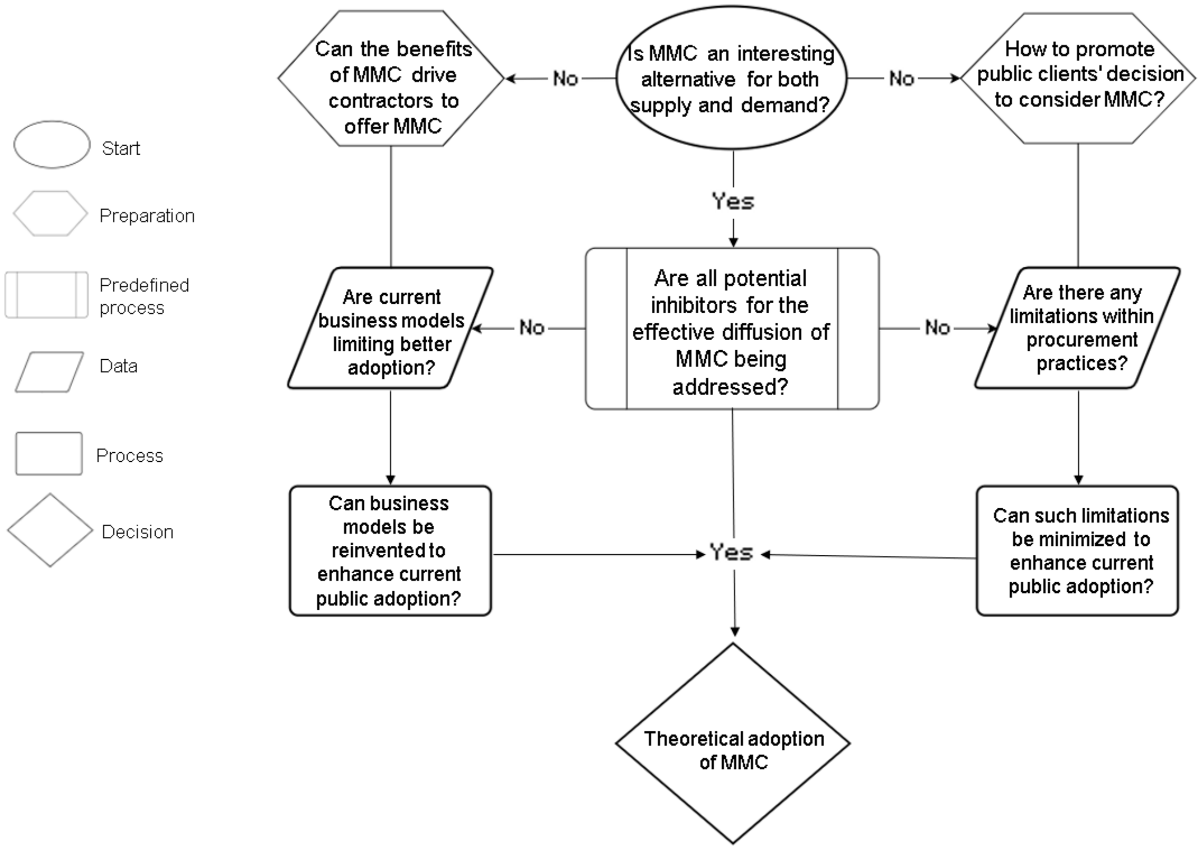

Figure 1: Theoretical framework of the Trading Dynamics Influencing Adoption of Innovation

Conclusion and Future Research

In the context of innovation, many aspects are to be considered to increase the uptake of MMC by the public bodies. To achieve this, a better understanding of the public client's behaviour is foreseen as different from normal clients due to exceptional influences on the standard decision-making process within their construction procurement. Such behaviour is influencing contractors towards bespoke practices alongside impacting the relationships with the supply side. Moreover, knowledge and awareness were an emerging function that can also act as a vital contributor towards the effectiveness of public clients' decisions. All those dynamics identified might be further enhanced with more understanding of the capabilities of public procurement frameworks, where those can act as integrators of innovation within the public clients' procurement strategies. This review identified that the context of where MMC is being investigated in the public sector is limited, creating a vital research gap, that is in return neglecting the important role that public clients can play to deploy innovation and embrace change represented by accepting MMC as effective alternative for conventional practices. Future research will focus on answering the following questions.

- Can public client behaviour influence contractors to embrace change and adopt innovation?
- Can reinventing existing business models enhance and promote innovation?
- Is there any activities within current public procurement practices unintentionally limiting innovation?
- How can the relation between public clients and contractors be enhanced to achieve better collaboration?
- Can public procurement frameworks govern the relationship of public clients and contractors to achieve effective trading dynamics?

This study aims, through a literature review, to understand the gaps within the public sector potentially limiting the adoption of innovation. Research on the impact of public procurement frameworks on the outcomes is limited (Lam & Gale, 2014). And such a gap in research is impacting the correlation between public clients and the supply chain, alongside uncertainty around the role that procurement frameworks can play to facilitate the adoption of innovation (Alharthi et al., 2015).

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Track 6

Performance Measurement

Accelerating building decarbonization: Houseowner's adoption behaviours analysis towards Residential Photovoltaic (RPV) systems in Singapore

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Abstract
Residential photovoltaic (RPV) systems are one type of building-integrated photovoltaics (BIPV) specialized for residential buildings, demonstrating a significant positive impact on reducing carbon emissions. The Singapore government targets to install at least two gigawatts of solar energy by 2030, but the development of RPV is slow. RPV adoption analysis is critical for RPV development as it helps understand the market and identify the driving factors. However, the existing study ignored the non-linear relationships due to the limitations of conventional data analysis approaches. On the other hand, Artificial Neural Networks (ANNs) are robust in dealing with non-linear relationships, but they lack interpretation capability, making ANNs unsuitable for adoption analysis. This study proposed a hybrid-ANN by integrating the behavior theory and the network weight-based method, aiming to find the key drivers of RPV adoption in Singapore by considering non-linear relationships in raw data. The proposed model was trained and tested by a survey study of RPV adoption in Singapore. The results show that the hybrid-ANN outperformed existing models in predicting and explaining adoption behaviors. Furthermore, this study reveals that consumers' pro-environmental, economic attitudes and social obligation are driving factors in determining consumers' intention to adopt RPV. The study contributes the methodology in RPV adoption analysis by developing a novel way to construct the behavioral theory hybrid-ANN, which can be extended to analyse the adoption of other Renewable Energy Technologies (RETs) across the globe.

Keywords
Adoption behaviors; Artificial Neutral Networks (ANNs); Residential Photovoltaic (RPV)

1 Introduction

Residential Photovoltaic (RPV) systems are solar energy technologies installed on the rooftop of residential buildings. Unlike large-scale PV systems in industrial or commercial buildings, RPV is scalable and distributed, demonstrating a significant positive impact on reducing carbon emissions in residential buildings. Residential buildings account for roughly 20% of greenhouse gas (GHG) emissions due to energy consumption, which usually takes around 20% of total energy usages in developed countries and more than 35% in developing countries (Kelly 2012, Goldstein *et al.* 2020). In Singapore, residential buildings consume more than 15% of the nation's electricity use (Hwang and Tan 2012). To reduce the carbon footprint, the Singapore government launches the Green Plan 2030, aiming to install at least two gigawatt-peak solar energy. However, RPV adoption is relatively slow. By the end of Q1 2020, the installed RPV capacity is 13.1 MWp, less than 4% of the total installed PV capacity after launching PV products for 12 years (EMA 2020). To further promote the RPV market expansion, an in-depth RPV adoption analysis for understanding the RPV market, driving factors, and potential barriers is necessary (Wolske *et al.* 2017, Palm 2018).

RPV adoption analysis results help policymakers identify policy implications to leverage RPV's development. Behavioural factors are prevalent in recent RPV studies because individuals' behavioural factors play a significant role in individual decision-making (Centola 2010, Masini and Menichetti 2012). Researchers exploited behavioural factors in explaining RPV adoption decisions by applying different psychological theories based on raw data from the futuristic or retrospective survey of household owners and processed with statistical analysis approaches (Bollinger and Gillingham 2012, Korcaj *et al.* 2015, Wolske *et al.* 2017). Korcaj et al.(2015) applied the Theory of Planned Behaviour (TPB) to predict consumers' intentions to purchase RPV in German with high accuracy. The results showed that consumers' positive attitudes are strongly influenced by beliefs that RPV would enhance social status, energy independence, and financial gain. Besides, many other psychological or social factors are analysed with outstanding findings, such as peer effect (Bollinger and Gillingham 2012), consumer's pro-environmental attitude (Wolske et al. 2017) and network structure (Zhang et al. 2018).

Current statistical analysis approaches in RPV adoption analysis ignored the non-linear relationships in the raw data when evaluating the impact of testing factors (e.g., age, education, income) on the dependent variable (e.g., adoption decision). The statistical analysis approaches, according to Alipour et al.'s (2021) review, consist of conventional regressions (linear regression, multivariable regression, logit regression), descriptive statistics, structural equation modelling (SEM) and various correlation tests (e.g., Analysis of Variance, T-test, F-test). An apparent drawback for the above statistical approaches is their incapable to consider non-linear relationships in RPV adoption (Walters *et al.* 2018). Artificial Neural Networks (ANNs) are good at finding hidden patterns in complex and non-linear problems, but they suffer from weak model interpretability (Partridge 2016). ANNs are made of several layers of interconnected neurons, including one input layer, one output layer and several hidden layers, similar to the human nervous system (**see Figure 1a**) (Mellit and Kalogirou 2008). ANNs have not been applied to RPV adoption analysis because researchers need to know the importance of factors to RPV adoption decisions, but the use of ANNs as "black models" makes it challenging to identify directly driving factors. In addition, a well-performing ANN model requires a large amount of raw data, which is not suitable for survey-based RPV adoption analysis with a small amount of data (typically less than 500). Moreover, the small amount of data and low data dimension may lead to the performance of ANNs being lower than other conventional techniques, such as linear regression (Kanungo *et al.* 2006).

This study proposes a TPB-ANN model associated with factors' explaining method to resolve the difficulties of applying ANNs in RPV adoption analysis. Herein, TPB, a classic psychological theory developed by Ajzen (2003), provides a practical consumer behaviour analytic framework with a three-hierarchy structure. The first layer consists of three direct components that are involved in consumers' rational decision-making process: (1) one's attitude towards the behaviour, (2) perceived social pressure to perform the behaviour (subjective norms), (3) one's assessment about the ability to perform it (perceived behavioural control). The second layer uses the intention of the behaviour to connect three components in the first layer. The last layer involves the consumer behaviour under the intention in the second layer and perceived behavioural control in the first layer (**see Figure 1b**). In addition, many researchers successfully applied TPB in their analysis of pro-environmental behaviours (Harland *et al.* 1999, Heath and Gifford 2002, Han *et al.* 2010). The TPB-ANN model uses the TPB's theoretical structure to build the ANNs layers' architecture (topology) by segregating and connecting specific neurons in different layers following TPB's components interactive relationships (**see Figure 1c**).

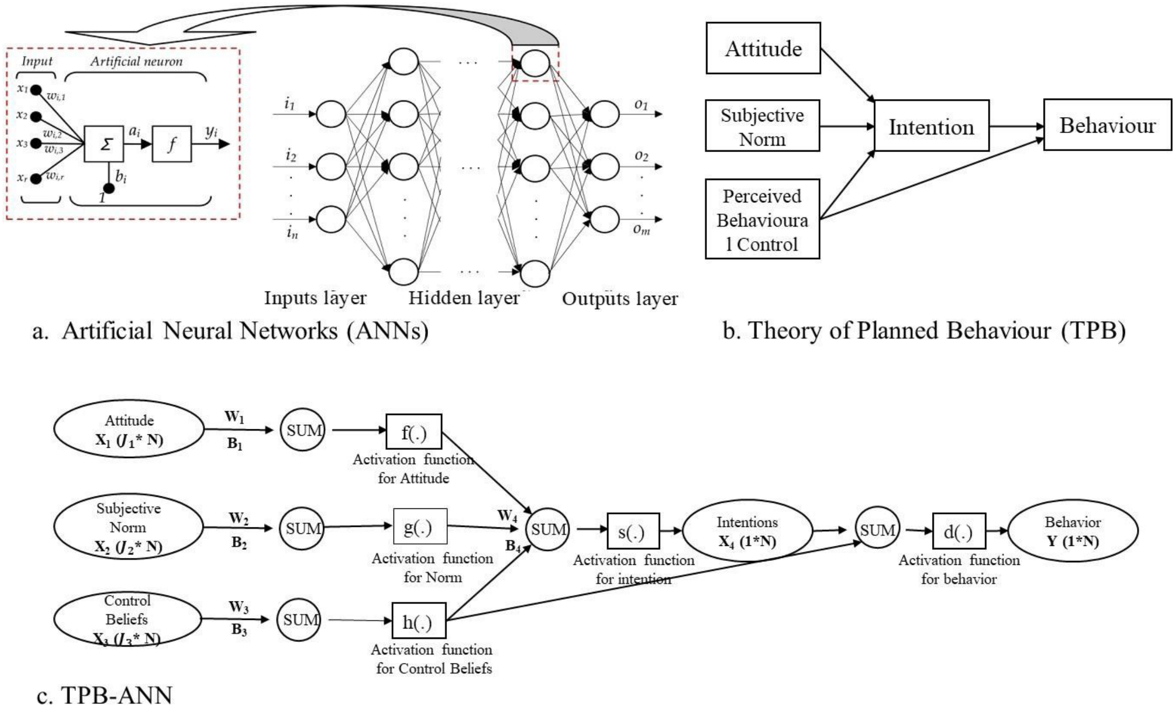


Figure 1. Illustration of TPB, ANNs and TPB-ANN

The Connection Weights (CWs) approach is selected to calculate factors' importance because its assumption aligns with the proposed TPB-ANN, which assumes that rationality can be learned and inherited by the topology of ANN through model training (Olden *et al.* 2004). CWs approach calculates factors' importance by multiplying weights of the trained ANNs backwards. To illustrate the non-linear capability and factors explanation ability of the proposed approach, a survey data with 293 valid responses measuring RPV adoption in Singapore was utilized for training and testing the proposed model. Model's prediction performance is compared with conventional regression models, such as linear regression (LR) and multilayer perceptron (MLP). In addition, the factors' importance is compared with path analysis result from structural equation modelling (SEM). LR is the most straightforward and cost-saving data analysing approach by fitting a linear plot with the lowest errors, and relationships between predictors and dependent variables are reflected by models' weights (Schmidt and Finan 2018). The MLP is a fully connected feed-forward ANN. Each neuron in one layer is connected to all neurons in the next layer, consisting of at least one hidden layer. SEM analysis utilizes the correlation matrix to analyse the structural relationship between measured variables and latent constructs, but it requires linear and normal assumptions in raw data, making it incapable of dealing with non-linear relationships in raw data (Schmidt and Finan 2018, Nam *et al.* 2020).

The study demonstrates the suitability of adopting ANNs in decision analysis through the development of a novel way to construct the TPB-ANN to solve the small data impact and "black-box" issue, which can be applied to analyse the factors driving the adoption of other Renewable Energy Technologies (RETs) across different geographical locations. In practice, the study analysed the non-linear relationships of RPV adoptions in Singapore and proposed instructive policy implications based on identified driving factors, which may help policymakers design the tailored energy policy to leverage RPV adoption.

2 Literature Review

2.1 Artificial Neural Networks in Adoption Analysis

ANNs have various applications in decision-making areas and usually are applied to forecast the human's judgment, based on factors that a person would use (Hill *et al.* 1994). Researchers in the early stage mainly applied ANNs in finance and investment. For example, Dutta and Shekhar (Dutta and Shekhar 1988) used different models to predict the ratings of corporate bonds and found that ANNs outperformed the linear regression. Later researchers applied ANNs in fault detection, which is proven effective because it can capture the hidden non-linear relationships in the raw data. With the tremendous increment of computing power in recent decades, more complex ANNs are invented to achieve more challenging tasks. For example, Convolutional Neural Network (CNN) implemented the convolution and pooling layer in the topology, making it superior in analysing visual imagery (Valueva *et al.* 2020). The Recurrent Neural Network (RNN) constructs the connections between nodes and forms a directed graph along a temporal sequence, making it applicable to sequence data (time-series, text, audio) (Sak *et al.* 2014, Valueva *et al.* 2020). However, it should be noted that the above-mentioned tasks generally place more weight on ANNs' forecast capability rather than its interpretability.

Using ANNs to illustrate and explain the adoption behaviours is complex, and existing researchers have chosen to implement other technologies or theories to help achieve the goal. Sim et al. (2014) utilized the sensitivity analysis to identify motivators from the trained ANNs in the study of mobile music acceptance in Malaysia and they compared the performance with Multiple Regression Analysis (MRA). They found that ANNs outperformed the MRA with smaller prediction Mean Square Error (MSE) because their ANNs captured the non-linear relationships in the survey data. Another interesting integration combines the SEM with ANNs to generate a hybrid SEM-Neural Networks approach (Tan *et al.* 2014). Tan et al. tried to identify drivers of behavioural intention to use mobile learning by applying a behavioural theory, the ANNs, and the SEM analysis. Firstly, they extended the behavioural theory with some hypotheses and collected survey data based on extended theory. Secondly, the SEM analysis was conducted to identify the causal relationships from the raw data. Finally, ANN associated with sensitivity analysis was utilized as a supplementary method to capture the non-linear relationships based on determined inputs and outputs from SEM results.

Current works explaining adoption behaviours with ANNs did not try to open the "black box" to illustrate the learned relationships from inside. Instead, they designed the sensitivity analysis to illustrate relationships between inputs and outputs by running the trained ANNs iteratively. Such practice may lead to a partial understanding of relationships or longer analysis time. Nevertheless, ANNs have some limitations besides low interpretability, such as slow convergence speed, arriving at the local minimum, over-fitting problems and relying on large data amounts and data dimensions (Kanungo *et al.* 2006).

2.2 ANNs' Connection Weights Approach

To address the "black-box" issue, some studies have been conducted on the factors' importance analysis, aiming to assess the variables' contributions in ANNs. Olden et al. (2004) conducted a robust comparison among the existing factors' importance assessment methods in ANNs. They concluded that the CWs approach outperformed the others in terms of similarity between identified importance and real ranked importance. The CWs approach is an ANN specified factor importance approach and calculates the importance of each input based on the weights in trained ANNs (Olden and Jackson 2002). **Figure 2** utilizes a simplified ANN model to illustrate the CWs calculation progress. Herein, the ANN consists of three predictors (inputs) and one hidden layer with two neural cells. Each predictor is fully connected with the cells in the hidden layer, and hence there are two input-hidden weights and one hidden-output weight for each predictor. The factor's importance is calculated by first multiplying corresponding hidden-output weight and input-hidden weight, and then sum the products, which is shown as **Figure 2**. CWs approach's performance depends on the distribution of the ANNs' weights and the topology. The CWs approach is implemented in this study for the factors importance assessment because its assumption is consistent with the proposed TPB-ANN.

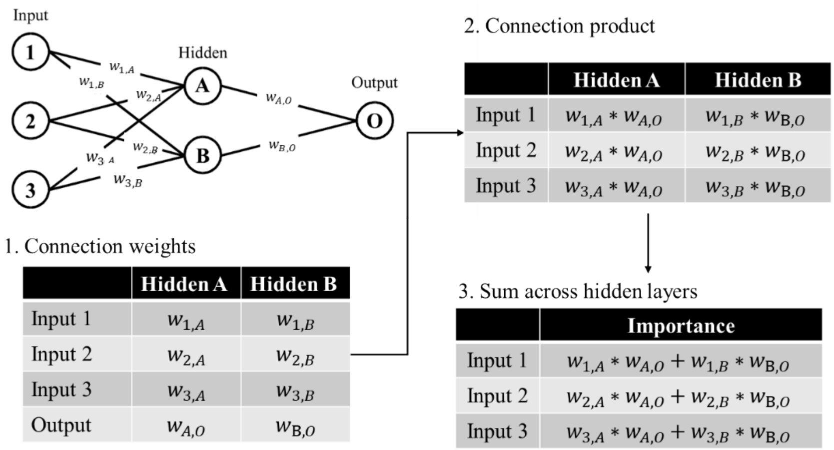


Figure 2. Example of Connection Weights for assessing predictors importance in ANNs

3 Research Methodology

The TPB-ANN is trained and tested based on the survey data, which is designed based on the TPB framework. **Figure 3a** shows the determined survey questions, and there are 18 questions (7-point Likert-scale from extremely disagree to extremely agree) with the extension of familiarity about RPV. Familiarity is essential in determining consumers' adoption behaviours, and some effective policy recommendations are proposed to increase the consumer's familiarity (Rebane and Barham 2011). Herein, the intention to adopt RPV was measured because there are few households adopted RPV in Singapore. The survey was sent via email, posted on social media, and distributed in train stations randomly to household owners in Singapore. The survey collections took three months, starting from December of 2019. There are in total, 314 responses were received, and 293 valid responses were left after verification. Given the determined data structure, the TPB-ANN model can be established by building the ANN's topology based on TPB's structure, which is shown in **Figure .3b**. Inputs are separated into four parts to feed in respective components in the input layer. The matrix *X* is used to denote the set of input vectors with $X.shape = (J, N)$. The sample size is *N* and the number of factors for each sample is J. Based on the TPB structure, input matrix *X* can be expressed as a matrix with $(J_1 + J_2 + J_3 + J_4) * N$ shape, while J_i $i \in (1,2,3,4)$ represents the number of factors in each TPB component defined in **Figure 3a**. There are two hidden layers followed by the input layer. The first hidden layer separates the neurons into four groups to match the input component *i*. Each group has m_i neurons, the independent active function, and a unique set of weights ($W_{Ji,mi}$) and bias (B_{Ji}). The first hidden layer of the proposed model can be expressed as Equation (1).

$$a_i = \sigma_i(W_{Ji,mi}^T * X_i + B_{Ji}),\ i = (1,2,3,4) \tag{1}$$

where, σ_i and a_i are the activate function and outputs for each input component i in first hidden layer. The size of output a_i is (m_i, N). Afterward, perspective outputs of the first layer components combined and fully connected to the second hidden layer with *k* neurons and weights set $W_{m,k}$. The "concat" function is applied, which simply full out join the four outputs matrix from the first hidden layer ($\bigcup_{i\in(1,2,3,4)} a_i$). The output layer is also fully connected with the second hidden layer with weight set $W_{k,I}$ and output vector Y ($Y.shape = (I, N)$). I measures different levels of RPV adoption intention respondents appeared in the survey data. Consumers' adoption intention can be normalized to a single value between -1 to 1 by averaging the scores of three intention questions. Afterwards, the intention value is categorized into I groups by doing the distribution fit because the value is not continuous and repeated. Hence, this is a multilabel classification problem.

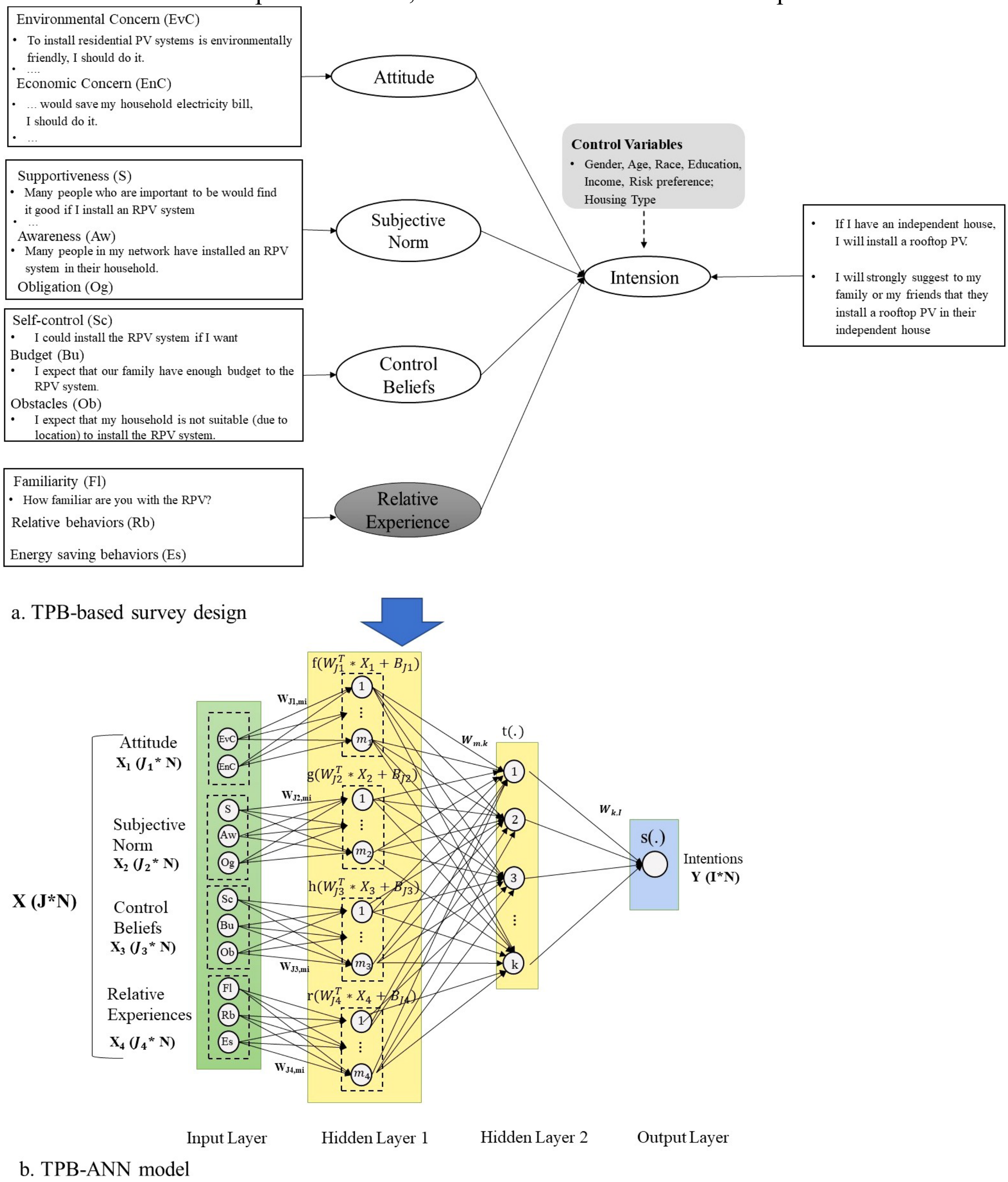


Figure 3 TPB based survey and TPB-ANN prediction model

After the model construction, this model needs to be tuned and trained. In this study, "relu" function is chosen as the active functions in hidden layers. "relu" function can significantly increase the model training speed by projecting the outputs into a piece function, which indicates the good "non-linear" process capability. For the output layer, the "softmax" function is applied to the final output matrix, which is the default active function for the classification problem. The number of the neurons of each input component and the second hidden layer are determined to be $m_i = 16\ i \in (1,2,3,4)$ and $k = 32$, respectively after balancing the training time and forecast accuracy. The loss function is calculated based on the cross-entropy loss function, which measures the degree of similarity between predicted results and actual values and its value will turn to zero if the prediction is the same as the actual. The "SGD" optimizer with a learning rate of 0.001 and decay of 0.0001 achieved the highest prediction accuracy. This study set up the pre-defined epoch numbers ($n_{iter} = 200$) to determine when to stop.

CWs approach helps identify the factor importance by backward calculating the product of the weights in the network. When calculating the CWs for TPB-ANN, the backward calculation needs to stop at the first hidden layer, split the weight product into four and then continue to calculate the weight for each factor. Suppose the CWs for input component i is denoted by CW_{Ji} ($CW_{Ji}.shape = (1, Ji)$). The trained weight set for component i in the first hidden layer is $W_{Ji,mi}$ ($W_{Ji,mi}.shape = (Ji, mi)$) and trained weight sets for the second hidden and output layers are $W_{m,k}$ ($W_{m,k}.shape = (m, k)$) and $W_{k,I}$ ($W_{k,I}.shape = (k, I)$) respectively. The $CW_{j,i}$ can be formulated shown as Equation (2) by referring to Olden and Jackson's (2002) work.

$$\bigcup_{i\in(1,2,3,4)} CW_{Ji} \cdot W_{Ji,mi} = W_{k,I}^{T} \cdot W_{m,k}^{T} \tag{2}$$

Where the notation "·" represents the dot product between two matrixes. $W_{k,I}^{T} \cdot W_{m,k}^{T}$ generate the weights product with shape = (I , m), which is consistent with the left side of the equation because $m = m_1 + m_2 + m_3 + m_4$. Therefore, the weights product $W_{I,m} = W_{k,I}^{T} \cdot W_{m,k}^{T}$ needs to be split into four weight sets ($W_{I,mi}$) based on the mi distribution before calculating the specific Connection Weights for factor j. The ultimate CWs for factor j is then calculated as follows.

$$CW_j \in \sum_I (W_{I,mi} \cdot W_{Ji,mi}^{T}),\ \ j \in (1,..J_i)\ and\ i \in (1,2,3,4) \tag{3}$$

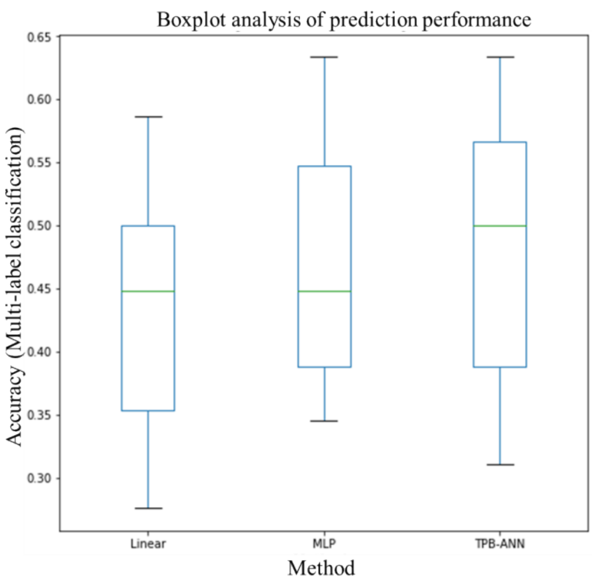
Where $\sum_I (W_{I,mi} \cdot W_{Ji,mi}^{T})$ generates the set of weight connections for factors in input component i with size (1, J_i)

4 Findings and Discussion

In this study, three models (LR, MLP, TPB-ANN) were tested using the same ten sets of training and testing data, and their prediction results were recorded and displayed in **Figure 4**. Accuracy in this study is calculated using the number of correct classifications dividing the total test. ANN models (MLP, TPB-ANN) outperformed the linear regression model in 8 out of 10 cases. The TPB-ANN model appeared to have dominant performance among three candidate methods in 7 out of 10 cases. The average and median value of TPB-ANN's accuracy is also the highest among the three models. This indicates that ANNs have better model forecast accuracy than linear models because ANNs can discover the non-linear relationship in the data. Compared with MLP, the TPB-ANN's forecast accuracy is higher, which may due to TPB-ANN model can effectively prevent the over-fitting issue because it made the "intended drop-out" operation.

Factors' importance in TPB-ANN is calculated based on the CWs approach and summarized across five intention groups in ten folds, which is shown in **Table 1**. To illustrate the effectiveness of the proposed factors' importance method, SEM was implemented to do the cross-validation. After conducting a series of rigorous data normality checking and cleaning the out of limit points, the SEM identified that "Attitude" and "SubNorm" are two significant components impacting the intention for RPV adoption directly. In addition, factors inside the two main components are significant to the corresponding component, which is shown in **Table 1**. TPB-ANN is able to identify the importance of each factor without any pre-processing, and the results revealed that TPB-ANN identified driving factors are consistent with the result from SEM. Besides, CWs approach can rank the factors according to their absolute importance to differentiate which factors are more impactful, while SEM cannot. The comparison shows the conveniences and feasibility of applying the CWs approach to explain factors' importance in the TPB-ANN model.

This study found that "Attitude" and "Subjective Norms" were two drivers that significantly influence the respondents' intention to adopt RPV in Singapore. The results reflected respondents who care more about RPV's possible environmental and economic improvements show more interest in RPV adoption, which is consistent with finding from Wolske et al. (2017) in their analysis of RPV adoption in the U.S. Inside the "Subjective Norms," the research shed light on the respondents' "Obligation," and "Supportiveness". Precisely, the obligation reflects respondents' sense of social responsibility, which was identified to play an essential positive role in promoting RPV adoption intentions. Respondents' obligation of RPV reflects the awareness of the consequences of RPV adoption, which was found to play a significant positive effect (Wolske et al., 2017). Consistent with past research, the research also concluded that the potential adopters were found to tend to install RPVs because of the peer's support because friends or relatives' support can help respondents gain confidence in RPV adoption.



Fold	Linear	MLP	TPB-ANN
1	0.50	**0.57**	**0.57**
2	0.50	**0.63**	**0.63**
3	0.50	0.53	**0.57**
4	0.41	0.55	**0.59**
5	0.38	0.45	**0.52**
6	**0.59**	0.34	0.34
7	**0.48**	0.41	0.41
8	0.28	**0.38**	**0.38**
9	0.34	**0.38**	0.31
10	0.34	0.45	**0.48**

	Linear	MLP	TPB-ANN
count	10	10	10
mean	0.43	0.47	**0.48**
std	0.10	0.10	0.11
min	0.28	0.34	0.31
max	0.59	0.63	0.63

Figure 4 Prediction accuracy results and boxplot in ten folds experiment

Table 1. Factors importance comparison between TPB-ANN and SEM

Method	lval	op	rval	Estimate	Std. Err	z-value	Count	p-value
SEM	Intention	~	Attitute	0.206	0.095	2.164	/	**0.0305***
	Intention	~	SubNorm	0.374	0.126	2.965	/	**0.003****
	EnC	~	Attitude	0.935	0.081	11.531	/	0
	EvC	~	Attitude	1	-	-	/	-
	Og	~	SubNorm	0.757	0.097	7.798	/	0
	Aw	~	SubNorm	0.797	0.106	7.542	/	0
	Sup	~	SubNorm	1	-	-	/	-
TPB-ANN	Intention	~	EvC2	0.14	0.34	/	50	/
	Intention	~	EvC1	0.17	0.28	/	40	/
	Intention	~	S2	0.19	0.25	/	30	/
	Intention	~	EnC2	0.11	0.24	/	20	/
	Intention	~	Og	0.18	0.23	/	50	/
	Intention	~	S1	0.15	0.23	/	30	/
	Intention	~	EnC1	0.11	0.22	/	20	/

* $P < 0.05$; ** $p < 0.01$

Based on the findings, this study proposes several policy implications to promote RPV adoption in Singapore. Firstly, attitude can help to categorize the target consumer types in different RPV development and diffusion phases. For example, our findings show that targeting environmentally conscious households in the initial adoption phase will help to grow the market. Secondly, the results emphasize the social supports in promoting RPV adoption, as highlighted by many researchers (Bollinger and Gillingham 2012, Zhang *et al.* 2018). The finding shows that the consumers' referral programs and word-of-mouth would be the most effective marketing strategies for innovations, especially in the initial adoption phase when most consumers know little about the product. Policymakers are suggested to display the role models in the relevant residential communities or encourage adopters to share their experiences in their networks by setting up various incentives.

5 Conclusions and Further Research

This study proposes a TPB-ANN associated with the CWs approach to analyse non-linear relationships in RPV adoption. The case study of RPV adoption in Singapore was applied to test the proposed approach's performance by comparing it with existing models (LR, MLP, SEM). The TPB-ANN showed outstanding performance in the intention forecasting and driving factors explanation. In addition, environmental concerns and social support are identified as the top two components impacting the consumer's RPV adoption in Singapore and corresponding tailored policy implications such as consumers' referral programs and role models, are suggested to promote RPV development.

Future research should focus more on the more profound analysis of the trained TPB-ANN model with various scenario analyses to discover more interesting findings from the model. In addition, the complete structure of TPB was not implemented and tested in this study due to the difficulty in measuring actual RPV adoption decisions in the survey study. ANNs' training process is time-consuming, and currently, there is no automated way to tune hyperparameters for better performance ANNs. Future works focusing on testing the complete set of TPB and developing the intuitive hybrid-ANN integrated data analytical platform will further support the outcomes of this study.

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Productivity of robotic excavators for caisson construction

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Abstract
Caisson foundation, which had been a popular foundation system in Hong Kong in 1970s and 1980s, was hand-dug by caisson workers. The advantages of using this construction method are cost-effectiveness and low mobilisation resources. However, as a result of airborne silica dust, the caisson workers working in the confined space of a hand-dug caisson may be exposed to the risk of getting pneumoconiosis. Thus, this construction method was banned by the Government in 1995. A robotic excavator was hence invented for replacing the caisson workers to deliver the excavation tasks. This new construction method can potentially improve the productivity performance of piling construction, while the workers' health can be guaranteed. Since the existing literatures focusing on benchmarking the productivity perfomance of using robotic excavators are very limited, this research study benchmarks the productivity of robotic excavator for caisson construction using site experiment data. The productivities of constructing five circular piling shafts using robotic-dug method and bored pile construction method are simulated and compared. The conclusion is drawn by discussing the cost-effectiveness using robotic-dug construction method.

Keywords
Caisson Construction, Process Productivity, Robotic Excavator.

1 Introduction

In Hong Kong, caisson construction using hand-dug construction method was invented in 1960s. The diameter of the caissons ranges from 1m to 3m typically. Construction involves hand excavation of a circular shaft by caisson workers. The excavation activity is started by excavating a circular shaft with approximately 900mm deep from the ground level. The stability of soil in a vertical cut condition is temporarily retained by arching effect of the soil. A concrete lining would be soon cast to retain the vertical soil surface. To cast the concrete lining, a circular formwork or mould within the caisson shaft is firstly installed followed by pouring concrete into the gap between the soil surface and the formwork. The gap, which in turn the thickness of the concrete lining/ring, ranges from 100mm to 150mm. Completing the procedures of soil excavation and concrete ring casting are usually the work-done of caisson workers in a working day. The procedures would be re-performed in the next working day to cast another concrete ring below the ring cast in the previous day. The shaft construction is continued until the desired founding level is reached (Figures 1, 2 and 3).

The Hong Kong Institution of Engineers (HKIE 1981) published “guidance notes on hand-dug caissons”. This publication defines the hand-dug caisson construction, including design principles, construction methods, sequence, process, and measures. The publication mentioned that the shaft excavation (including soil excavation, placing steel mould of lining, and concreting the lining) at about or slightly less than 1000mm depth in favourable ground condition could be completed within a working shift (i.e., from 08:00 to 18:00). In other words, practically, the productivity is determined as 900 mm/day to 1000 mm/day, which is limited by daily working hours. Although the hand-dug method has the advantages of cost-effectiveness, low machinery requirement, high mobilisation and flexibility in coping with complex site conditions and limited working space (HKIE 1981), this construction method was banned by the Hong Kong Government since 1995 because of the high risk of infecting caisson workers with pneumoconiosis.

Thanks to the advancement of robotic technologies, an in-house robotic excavator for caisson excavation was prototyped by the research team (Guan *et al.* 2021). This innovation helps in replacing those caisson workers who perform the excavation tasks to potentially improve the productivity while reducing the hazards to the workers. Nonetheless, the past research works related to the caisson construction are highly limited. As such, this research study will be the first one to measure, determine, and analyse the productivity benchmarks of caisson excavation performed by a prototyped excavator. The following sections are structured as followed. The existing literatures are reviewed in context of the productivity benchmarks for hand-dug caisson excavation. The methodology is given for capturing the productivity of robotic excavator using time study technique on site, followed by simulating project process driven by the benchmarked productivity. Then, comparisons of excavating circular shafts using robotic-dug method and bored pile method are discussed. The conclusion is drawn by discussing the competitiveness of using the robotic arm for piling construction.

Figure 1: Starting of a caisson (Law 1981)

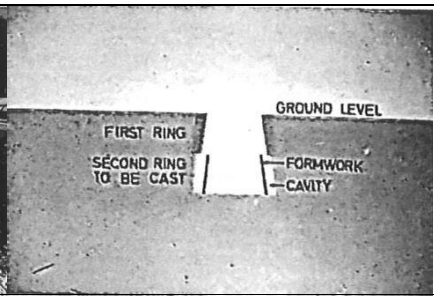

Figure 2: Procedure for placing concrete rings (Law 1981)

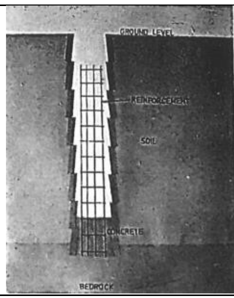

Figure 3: Diagrammatic view of a caisson (Law 1981)

2 Literature Review

There are limited research endeavours focused on deriving productivity benchmarks for planning and managing foundation construction projects. For example, Zayed and Halpin (2001, 2005a, 2005b) benchmarked the productivity of piling process using questionnaires and expert interviews. They developed simulation models to present and visualise the piling process in a construction cycle. Given the benchmarked productivity as the data inputs for simulation models, the productivity, time, and cost of piling projects were predicted. The authors developed the charts aiming to facilitate the contractors in bidding and controlling the budget of piling projects. Furthermore, the authors studied the system productivity, cycle time, and project cost of piling projects by combining the use of simulation techniques and artificial neural networks. The models were validated and proved their robustness.

Similarly, Zayed (2005) developed productivity index using simulations to quantify the impact of subjective factors on the process productivity when constructing continuous flight auger piles. Charts were developed for practitioners to quickly estimate the system productivity, cycle time, and project cost. Chong *et al.* (2006) collected the data of constructing the concrete piles from 25 highway projects. The authors developed logarithmic models to characterise the relationships between production rates and pile length. Jiradamkerng *et al.* (2011) used regressions to characterise the relationship between the productivity and critical factors, such as pile driving work and joining of two-piece pile by welding, for square precast concrete pile construction. They developed synthetic equations for determining the project time and work productivity in connection with the type and size of piles. As such, the system productivity of robotic-dug excavation using operations simulation, driven by benchmarking the time of performing excavator's motions, is yet to be explored.

3 Methodology

3.1 Prototype Robotic Excavator

A robotic excavator was prototyped with the aim of replacing the excavation tasks performed by caisson workers working in the pile shaft (Guan *et al.* 2021). Figure 4 illustrates the design of robotic excavator to perform the excavation for constructing the caisson shafts. Figure 5 shows the setup of the site trial. The data of robot performance is collected when excavating a caisson with 1.5m to 2.5m diameter and a depth not exceeding 3m. The robot replaced the manual excavation works while the caisson rings are casted by experienced concreters.

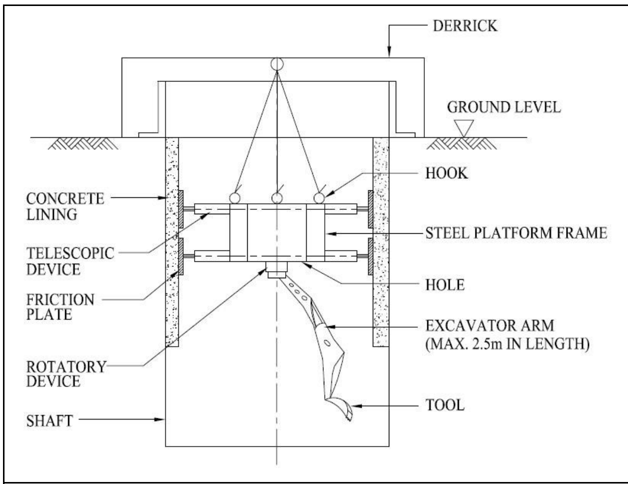

Figure 4: Design of robotic excavator

Figure 5: Setup of site trial

3.2 Methodology

Table 1 tabulates the steps for investigating the excavation productivity using the prototyped robotic excavator.

Table 1: Steps for determining the productivity of using robotic excavator

Steps	Work items	Actions	Details
1	Design and manufacture the prototyped robotic excavator.	Research and review current construction technology of available excavators which are suitable for prototyping a robotic excavator.	
2	Design and conduct site trials to test the functionality of the excavator.	Conduct full-scale experimental setup to fully test the functionality of the excavator.	
3	Determine the duration of the motion of the excavator to measure the cycle time of one excavation cycle.	Perform video recording when conducting excavation tasks. The motions of excavator are identified. The time of each motion is determined using stopwatch. The cyclic process of the excavation is identified. The cycle time which composed of the motion time are determined.	Section 3.3.
4	Develop simulation model to estimate the construction time of a caisson according to measured data.	Analyse execution sequence of the motions of a construction cycle. The measured time of excavation motion is used as the data inputs for developing simulation models.	Section 3.3.
		Use simulation software to develop a simulation model for estimating production rate and project time of caisson construction using robots.	Section 4.3. Section 4.4.
5	Conduct a case study to shed light on the competitiveness of using the prototyped robotic arm against other construction technology in piling construction.	Collect productivity data of shaft excavation using bored pile method.	Section 4.2.
		Carry out a comparison on shaft excavation performance between robotic-dug method and bored pile method with respect to resource configurations.	Section 4.5.

3.3 Time Study on Excavation Motions

Excavation was repeatedly performed by the robotic excavators in order to assemble the datasets for determining the work productivity. Table 2 shows the benchmarks of the duration of robot motions. A bucket at the end of the excavator arm is of a volume at about $0.015m^3$. A drum-skip which transports the soil spoil from caisson bottom to the ground level is $0.2m^3$ (HKIE 1981). The numbers of cycle to fill-up the drum-skip is therefore 15. The excavation cycle for transporting the soil spoil from caisson bottom level to the ground level with respect to caisson diameter is therefore formulated as Equation (1).

Table 2: Measured cycle time of excavation motions

Motions	Time (sec)	Descriptions
Rotation of robotic arm (Figure 5)	13	360° rotation
Extension and extraction of upper hydraulic jack	7	From full extraction to full extension
	7	From full extension to full extraction
Extension and extraction of middle hydraulic jack	4	From full extraction to full extension
	4	From full extension to full extraction
Extension and extraction of lower hydraulic jack	2.5	From full extraction to full extension
	2.5	From full extension to full extraction
Cycle time for one excavation motion (Figures 6a to 6f)	45	N/A

$$\text{Number of cycle} = \left(\frac{\phi^2 \times \pi}{4} \times d \right) \Big/ 0.2 \quad (1)$$

where ϕ = diameter of pile/caisson, d = depth of excavation

3.4 Simulation of Excavation Cycles

In this research study, simplified discrete-event simulation approach (SDESA) which was invented by Lu (2003) with further software redevelopment on user-interface and user-experience by Siu (2020), is used. The SDESA platform is used to simulate the construction schedules by mimicking the process workflows executed with the limited workers. What-if scenarios can be assumed to generate any better alternative solutions. In addition, the criticality of resources can be estimated for enhancing the project productivity and resource utilisations.

4 Practical Case Study

4.1 Background

To compare the time of pile shaft excavation using robotic-dug and bored pile methods, an on-going building project constructing five 1.5 diameter bored piles is used. The excavation time using the robot is estimated using traditional time study technique as shown in Figure 6(a) to Figure 6(f). The SDESA platform was used to simulate the excavation time using robots. To perform the simulation, work activities, robot motions, process and sequence, activity duration, and required resources are defined. Notably, the excavation time using bored pile method is extracted from this project.

(a)

(b)

(c) (d)

(e) (f)

Figure 6

4.2 Time and resources of shaft excavation using bored pile method

Productivity data about shaft excavation by bored pile method is summarised in Table 3. Due to the limited working space within the site, 1 set of resource (1 oscillator plus 1 crawler crane) is only allowed. The average productivity is 167.4 mins/m.

Table 3: Productivity data and resource of bored pile method

Pile number	Shaft excavation depth	Average mins / metre length	Resources
BP1	52.3m (+2.6mPD to -43.9mPD)	150.3	1 oscillator, 1 crawler crane.
BP2	To be commenced	-	1 oscillator, 1 crawler crane.
BP3	33.0m (+3.0mPD to -44.7mPD)	169.6	1 oscillator, 1 crawler crane.
BP4	52.0m (+3.0mPD to -44.5mPD)	182.4	1 oscillator, 1 crawler crane.
BP5	To be commenced	-	1 oscillator, 1 crawler crane.

4.3 Process of shaft excavation using caisson-robot

Figure 7 shows the proposed simulation model which presents construction process by sequencing work activities performed in 1 excavation cycle. Caisson shaft excavated by robots was formed on interval basis (900mm to 1000mm), followed by casting concrete lining (i.e., caisson ring). The abovementioned cycle will be repeated on interval basis from the ground level to the founding level assuming that no rock is encountered in the shaft.

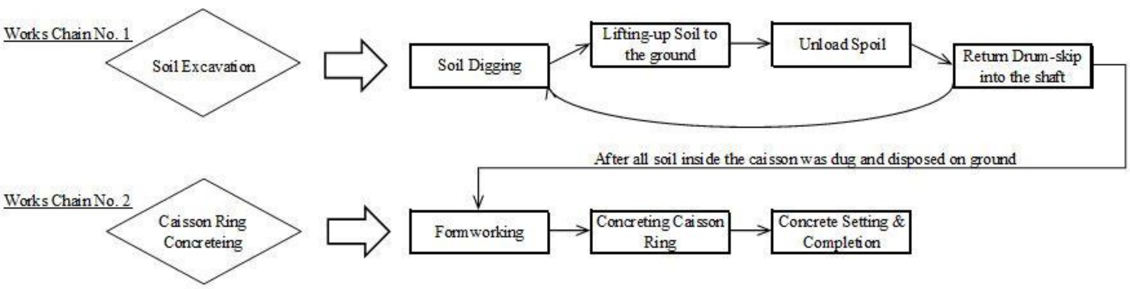

Figure 7. Activity chains for a construction of caisson shaft ring by robotic-dug method

4.4 Time and resources of shaft excavation using caisson method

The motion time of digging soil using caisson robot is given in Table 2. The time and resources of other activities to complete a shaft excavation cycle are tabulated in Table 4. The data is captured from an experienced caisson worker with more than 20 years of experience.

For a 1.5m diameter caisson, the volume of soil spoil to be excavated for a depth of 1m is calculated as $1.767m^3$. In accordance with Equation (1) in Section 4.2, the numbers of cycle for Activity 1 to 4 shall be repeated for 8.8 times before moving to Activity 5. To take practical consideration into account, 10 cycle simulation for Activity 1 to 4 is to be adopted. Finally, the mentioned data and configuration were input into SDESA to simulate the excavation time required for robotic-dug method

Table 4: Productivity data and resource of robotic-dug method

No.	Activity	Time (mins) (min. / mean / max.)	Resources
1	Soil digging to drum-skip	10 / 12 / 15 (from 0m to 15m deep)	1 robot 1 drum-skip (at $0.2m^3$)
		12 / 14 / 17 (from 15m to 30m deep)	
		15 / 18 / 24 (from 30m to 45m deep)	
2	Lifting-up soil in drum-skip to the ground	2 / 3 / 4	1 robot 1 above-ground worker 1 drum-skip (at $0.2m^3$)
3	Unload spoil	2	
4	Return drum-skip into the shaft	2 / 3 / 4	
5	Formwork	20 / 30 / 40	1 steel formwork
6	Lining concreting	40 / 50 / 60	
7	Lining concrete setting	-	-

4.5 Results and discussions

This sub-section presents the excavation time using bored pile and robotic-dug method. Excavation of a 45m deep shaft is adopted as the baseline of the pile length for comparison since the maximum caisson depth in Hong Kong was 45m deep (HKIE 1981). For the bored pile method, the excavation time (total time: 37671.9 mins) is given in Table 5. For robotic-dug method, the simulation results are summarised in Table 6 (total time: 14950.6 mins).

Table 5: Excavation time of bored pile method

Bored pile no.	Ave. mins / metre length (mins / m)	Tentative length (m)	Total excavation time (mins)
BP1	150.3	45	6763.3
BP2	167.4	45	7534.4
BP3	169.6	45	7633.5
BP4	182.4	45	8206.4
BP5	167.4	45	7534.4

Table 6: Excavation time of robotic-dug method (based on 1 set of resource)

Interval of excavation depth	Mean mins / metre length for a typical 1000mm deep excavation cycle (mins / m)	Total length of the interval (m)	Total excavation time (mins)
0m ~ 15m	303.3458	15	4550.2
15m ~ 30m	323.3458	15	4850.2
30m ~ 45m	370.0150	15	5550.2

Table 7: Comparison between bored pile method and robotic-dug method

Method	Sets of resources	Excavation time for a 45m deep shaft as per 1 set of resource (mins)	Required no. of cycle for the shaft excavation of 5 nos. of piles/caissons	Total excavation time
Bored pile method	-----	-----	-----	37671.9
Robotic-dug method	1	14950.6	5	74753.0
	2	14950.6	3	44851.8
	3	14950.6	2	29901.2

The excavation time using robotic-dug method with 1 set of resources is found not competitive to the bored pile method (Table 7). However, the productivity performance of robotic-dug method is able to catch-up or even outperform to that of bored pile method if additional sets of resources are available (Figure 8). Constrained by site area (14.7m by 7.4m), the site is fully occupied by 1 crawler crane and 1 oscillator so that the productivity performance of bored pile method is limited. However, robotic-dug method requires less working space. If more than one shaft can be excavated concurrently, the overall productivity using robotic-dug method can be improved. As such, the robotic-dug method is potentially a more competitive option for tiny and congested sites which are common seems in Hong Kong.

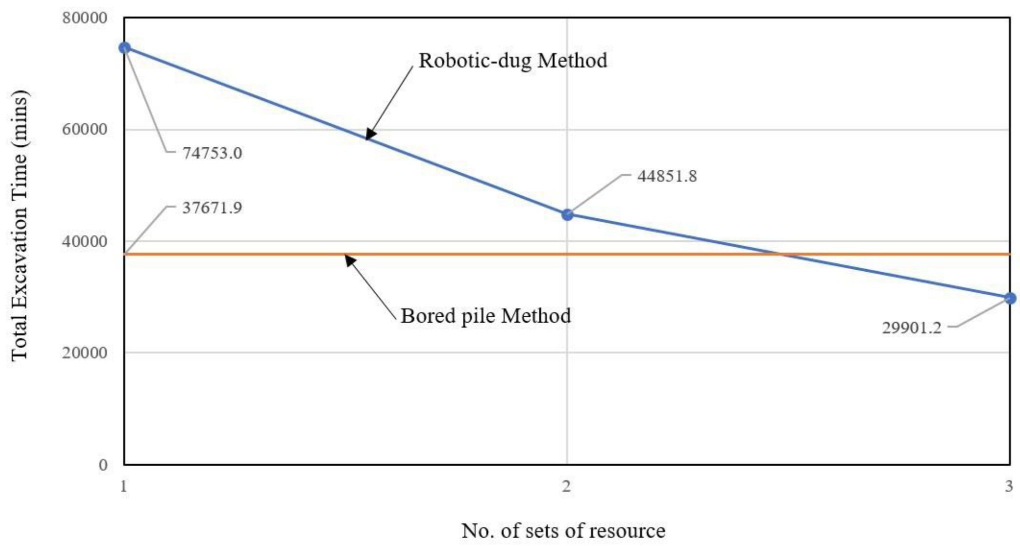

Figure 8. Time comparison between bored pile method and robotic-dug method

5 Conclusions

In this research study, the productivity of caisson shaft excavation performed by robotic excavator was successfully benchmarked based on productivity time study and operations simulation. The productivity benchmarks using bored pile method and robotic-dug method were contrasted based on 5 bored piles construction on a tiny site. The result showed that the productivity performance on shaft excavation using robotic excavator (74753.0 mins) is not competitive to the one of bored pile method (37671.9 mins). Thanks to the mobilisation features of robotic excavator, if more sets of resources (2 sets, 3 sets) for robotic-dug method are given, the productivity performance using robotic-dug method (44851.8 mins, 29901.2 mins) is able to outperform its excavation performance to that of bored pile method. This productivity characteristic enables robotic-dug method to be effective and competitive for tiny construction site commonly found in Hong Kong. The research team envisioned that the productivity of using robotic method will be further improved by refining the mechanical configurations of the robotic excavator (Mark II version) for caisson construction.

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Assessing the Impact of Smart Technologies on Project Management: The Case of Singapore

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Abstract
Integrated, digitalized and automated value chains can be recognized as the fundamental characteristics of the Fourth Industrial Revolution and can overcome many challenges faced by industries. To effectively utilize smart technologies in the construction industry, it is essential to understand how these technologies impact project processes. Hence, this study aims to provide a better understanding of the impact of smart technologies on project management knowledge areas to anticipate the changes in project management processes. This study has the following research objectives: (i) investigate the smart technologies with the greatest impact on project management; (ii) assess the specific project management knowledge areas that will be significantly affected by the technologies; and (iii) statistically analyze if organizations of different sizes perceive the impact on project management knowledge areas differently. To achieve these objectives, a comprehensive literature review and pilot interviews with industry experts were first carried out, followed by a survey and post-interviews. The results indicated that the smart technologies with the greatest impact on project management were autonomous vehicles, robotics, cyber-physical system, Internet-of-Things and big data, which were largely contributed by the changes in how information has been collected, processed and utilized, and the automation of work processes. All project management knowledge areas were also found to be impacted by the smart technologies at varying degrees, with perceived differences among organizations of different sizes in several smart technologies on project management knowledge areas. The findings of this study provide better understanding of how the smart technologies impact project management, serving as starting points to anticipate and make necessary changes to project management processes in order to maximize the potential of smart technologies and ultimately improve the performance of the construction industry.

Keywords
Impact of technologies, Project management knowledge areas, Smart technologies

1 Introduction

The technologies of Fourth Industrial Revolution (4IR) enable the convergence of the physical and cyber paradigms, leading to the integration, digitalization and automation of entire value chains (Kamble *et al.* 2018). The integration of entire value chains presents the potential to improve performance of industries, when complemented with streamlined organization and work processes and collaboration within business ecosystems (Leviäkangas *et al.* 2017). While the nature of the construction industry has led to fragmentation and a general resistance towards change, the integration of the construction value chain presents huge potential to improve the performance of the industry (Sepasgozar *et al.* 2016). In particular, effective project management was found to be a critical project success factor and significantly influences project performance (Wanivenhaus *et al.* 2018). However, existing studies on smart technologies in the construction industry typically focus on the specific applications of smart technologies or on improving the performance of the technology applications. Hence, this study aims to provide a better understanding of the impact of smart technologies to allow practitioners to anticipate the changes in project management processes. This study has the following research objectives: (i) investigate the smart technologies with the greatest impact on project management; (ii) assess the specific project management knowledge areas that will be significantly affected by the technologies; and (iii) statistically analyze if organizations of different sizes perceive the impact on project management knowledge areas differently. This study is conducted in the Singapore construction industry to complement the Construction Industry Transformation Map, established by the Singapore government to drive the adoption of smart technologies to improve the productivity and performance of the industry (Building and Construction Authority 2017). The findings of this study will allow organizations and project managers looking to implementing smart technologies to anticipate the changes in project management processes and better prepare themselves and facilitate the digital transformation of the construction industry.

2 Literature Review

Smart technologies associated with the 4IR include Cyber-Physical System (CPS), Internet-of-Things (IoT), Big Data (BD), robotics, Autonomous Vehicles (AV), Augmented Reality (AR), Virtual Reality (VR), Additive Manufacturing (AM), blockchain and laser scanning (Oesterreich and Teuteberg 2016; Kamble *et al.* 2018; Akhilesh 2020). These technologies can be used to digitalise and automate work processes by enabling the self-organisation and self-execution of work tasks, and have been commonly referred to as smart technologies (Akhilesh 2020). These smart technologies can be used in several aspects of construction projects to improve the performance of project management. Project management typically consists of ten knowledge areas as highlighted in project management standards, namely – (i) project integration management; (ii) project scope management; (iii) project schedule management; (iv) project cost management; (v) project quality management; (vi) project resource management; (vii) project communications management; (viii) project risk management; (ix) project procurement management; and (x) project stakeholder management (International Project Management Association 2015; Project Management Institute 2017).

In particular, CPS and IoT may be used for real-time monitoring and control on-site and along the supply chain, enabling the access to real-time project information for viewing, managing, sharing and collaborating from any location (Akanmu and Anumba 2015; Zhong *et al.* 2017). This changes the way project information is collected, processed, analyzed, communicated, and utilized by project stakeholders. BD processes and analyzes large volume, variety and velocity of data, which can impact all project management processes as both real-time and historical project data can be utilized to optimize and automate project processes (Bilal *et al.* 2016). AV and robotics automate work processes which reduces safety risks, improves consistency and changes the way workers interact with one another as dangerous and routine works can be conducted with the assistance of robots or AVs (Oesterreich and Teuteberg 2016; Chen *et al.* 2018). AR and VR enable project stakeholders to explore the 3D model and collaborate with one another, changing the communication medium among project stakeholders (Chi *et al.* 2013; Oesterreich and Teuteberg 2016). AM allows for printing of 3D components based on a digital model, enabling design freedom and shifts work processes off site (Kothman and Faber 2016). Blockchain can be used to automate contract execution upon fulfilment of agreed conditions, improving trust among project stakeholders and enables teams to be formed across geographical borders (Turk and Klinc 2017). Finally, laser scanning can be used to automatically collect 3D geometric information of as-built conditions to develop a 3D model to identify discrepancies of the as-built and as-planned models and site survey (Bosche *et al.* 2009). This can improve the efficiency of site surveys and enables timely identification of discrepancies, reducing reworks (Oesterreich and Teuteberg 2016). A summary of the smart technologies and the knowledge areas expected to be impacted is shown in Table 1.

Table 1. Summary of smart technologies and knowledge areas expected to be impacted

Smart technologies	**Applications**	**Knowledge area expected to be impacted**
Cyber-physical system and Internet of things	Real-time monitoring and control on-site and along the supply chain (Akanmu and Anumba 2015; Zhong *et al.* 2017)	All project management areas
Big data	Analyse real-time and historical project data to optimise and automate project processes (Bilal *et al.* 2016)	All project management areas
Autonomous vehicles and robotics	Automate work processes (Oesterreich and Teuteberg 2016; Chen *et al.* 2018)	Project schedule management, project cost management, project quality management, project resource management, project risk management
Augmented and virtual reality	Enable project stakeholders to explore the 3D model and collaborate with one another (Chi *et al.* 2013; Oesterreich and Teuteberg 2016)	Project integration management, project scope management, project schedule management, project cost management, project quality management, project risk management, project communications management, project stakeholder management
Additive manufacturing	Print 3D components based on digital model (Kothman and Faber 2016)	Project scope management, project schedule management, project cost management, project quality management, project communications management, project risk management, project procurement management, project stakeholder management
Blockchain	Automate contract execution (Turk and Klinc 2017)	Project schedule management, project cost management, project quality management, project communications management, project risk management, project stakeholder management
Laser scanning	Automatically collect 3D geometric information of as-built conditions to develop 3D model (Bosche *et al.* 2009)	Project integration management, project scope management, project schedule management, project cost management, project quality management, project communications management, project stakeholder management

3 Research Methods and Data Presentation

The research process consists of four steps. In Step 1, a literature review was conducted to understand the use cases of smart technologies in construction projects and the impact on project management to develop a survey questionnaire to gather the opinions of practitioners. Pilot interviews were carried out with industry experts to validate the survey questionnaire in Step 2. Step 3 was to administer the survey questionnaire to industry practitioners. The survey was sent to 600 target respondents and a total of 73 responses were received. The survey response rate is 12.1% and is within the norm of Singapore's survey response rate (Liao and Teo 2019). In addition, valid statistical analysis can be conducted as the total number of valid responses is more than 30, where the central limit theorem holds through (Ott and Longnecker 2016). Furthermore, with a sampling frame of at least 500 and at least 50 valid responses, low response rates do not equate to nonresponse bias (Curtin *et al.* 2000; Keeter *et al.* 2000; Fosnacht *et al.* 2017). The survey respondents include project managers (69.86%), architects (23.29%) and directors (6.85%), in which more than half of them (58.90%) have more than ten years of experience in the construction industry. In addition, the organizations comprise of small and medium enterprises (SMEs) (58.9%) and large enterprises (41.1%).

In Step 4, analysis of the responses was conducted through Statistical Package for the Social Sciences (SPSS) to determine the level of impact of smart technologies on project management knowledge areas. Shapiro-Wilk test was used to test the normality of the sample and indicated that the data is non-normally distributed. Mean rank analysis and one sample Wilcoxon-signed rank test were conducted to assess the significance of the impact of smart technologies on project management knowledge areas. To assess if organizations of different sizes perceive the impact on project management knowledge areas differently, the Mann Whitney U test was conducted.

4 Findings and Discussion

Table 2 shows the summary of the results from the mean rank analysis and Mann-Whitney U test among organizations of different sizes. The one-sample Wilcoxon-signed rank test indicated that all smart technologies impact project management knowledge areas, albeit at varying degrees. Based on the mean rank analysis, the smart technologies that have the greatest impact on project management knowledge areas were found to be AV and robotics, CPS and IoT and BD.

The top smart technologies that have the greatest impact on project management knowledge areas were found to be AV and robotics. This finding is expected as the construction industry is one of the industries with the lowest productivity rates due to the high level of uncertainty and reliance on manual labor, and is often known as a “dirty, dangerous, and difficult” industry (Yap and Lee 2020). Highly dangerous and routine works can be automated and conducted by AVs and robots, overcoming the challenges of low productivity and high safety risks. Accordingly, the top project management knowledge areas that were perceived to be impacted by AVs and robotics were found to be project quality, schedule and cost management. Automation of work processes can ensure consistency of works, reducing human errors and influences of fatigue, resulting in improved quality and increased certainty in the prediction of project duration and costs of work tasks (Chen et al. 2018). Furthermore, AVs can enable more holistic monitoring of the projects with the improved access to hard-to-reach or dangerous areas for human workers and consistency of data collected (Chen et al. 2018). However, in order to automate work processes, there may be shifts in workloads towards the detailed planning and monitoring of robotic systems in the earlier project phases (De Soto et al. 2019).

The next top smart technologies that greatly impact project management knowledge areas were found to be CPS and IoT. CPS and IoT were found to impact project communication, stakeholder and integration management the most. This finding is in alignment with the fundamental characteristic of the 4IR, which supports the integration of entire value chains, hence improving communication among stakeholders. Currently, the construction industry is very fragmented, with multiple stakeholders involved in the project operating in an environment with poor information transfer (Fernández-Solís *et al.* 2015). Several revisions of project information may be circulating among the project team, with duplicated or obsolete versions. Hence, the integration of the value chain can greatly improve project communication, stakeholder and integration management, where project stakeholders can now have access to the same updated project information from any location for communication (Oesterreich and Teuteberg 2016). Furthermore, existing construction processes do not support collaboration among stakeholders and require changes in communication processes among project stakeholders (Hwang *et al.* 2020). The digitalized and integrated construction value chain also increases transparency, which can increase trust among stakeholders and further improve project performance (Li *et al.* 2019).

Finally, BD was also found to impact project management knowledge areas significantly. Similar to CPS and IoT, BD was found to impact project communication, stakeholder and integration management the most. This could be because BD may be an enabling technology to support the real-time processing and analysis of collected data in the CPS and IoT network (Oesterreich and Teuteberg 2016). As construction projects are exposed to a high level of uncertainty such as bad weather, material and labour shortages, especially in the early phases of the projects, BD can be utilized to analyze historical project data to aid in project schedule and cost planning. Currently, project schedule development and cost estimation relies heavily on the experience of the planner (Project Management Institute 2017). The availability of data support in the development of project schedule and estimation of project costs can improve the accuracy of the developed schedule and cost budgets as biases based on the past experiences of the schedule planners and cost estimators may be reduced. Besides that, BD also impacts project integration management, in particular, change management, as the effects of project changes on project schedule, scope and risks can be assessed to determine the impact of the project change on overall project outcomes and select an optimal response to project changes (Bilal *et al.* 2016). Apart from the analysis of project information, BD can also enhance data visualization which allows for easier understanding in the decision making process. Overall, BD provides the platform for the project team to make data-driven decisions by executing analysis on historical and real-time data and enhances the visualization of the analysed data to improve communication among the project stakeholders.

The results of the Mann-Whitney U test indicated that SMEs and large enterprises perceived the impact of CPS, IoT and BD on project integration management, AV and robotics on project quality management, and laser scanning on project schedule and quality management differently. In particular, respondents from SMEs perceive the impact of these smart technologies on the project management knowledge areas to be less than large enterprises. While SMEs may have less resources to invest in new technologies, SMEs are typically more flexible and open to innovations to stay competitive (Guo and Cao 2014; Liao and Barnes 2015; Whyman and Petrescu 2015). Large enterprises may have established standard operating procedures to ensure consistency and may perceive the impact to be greater (Sageder and Feldbauer-Durstmüller 2019). Hence, the results are expected as SMEs have to embrace innovations to stay relevant and large enterprises have to uphold their reputation with consistent quality and performance, which may contribute to the differences in the perceived impact of the smart technologies on project management knowledge areas.

Table 2. Summary of the perceived impact of smart technologies on project management knowledge areas

	CPS/ IoT			BD			AV/ Robotics			AR/ VR			AM			Blockchain			Laser scanning		
	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW	M	R	MW
Project Integration Management	4.17	3	0.031*	4.17	3	0.050*	4.13	5	0.554	4.00	1	0.601	4.02	5	0.850	4.13	3	0.953	4.12	2	0.807
Project Scope Management	4.11	4	0.176	4.12	4	0.126	4.11	6	0.597	3.90	4	0.855	4.02	5	0.850	4.11	4	0.868	4.13	1	0.929
Project Schedule Management	3.90	6	0.075	3.86	6	0.292	4.39	2	0.052	3.60	8	0.814	4.41	2	0.102	3.64	6	0.530	3.84	5	0.043*
Project Cost Management	3.63	9	0.873	3.64	9	0.504	4.32	3	0.190	3.50	9	0.685	4.32	3	0.367	3.46	9	0.180	3.46	8	0.293
Project Quality Management	3.76	7	0.407	3.72	7	0.687	4.46	1	0.030*	3.82	6	0.497	4.43	1	0.086	3.53	8	0.780	3.76	6	0.017*
Project Resource Management	3.57	10	0.186	3.53	10	0.165	3.58	8	0.453	3.90	4	0.424	3.50	9	0.477	3.39	10	0.338	3.27	10	0.364
Project Communication Management	4.35	1	0.053	4.37	1	0.120	3.56	9	0.507	3.92	3	0.278	3.27	10	0.516	4.17	1	0.322	4.02	4	0.843
Project Risk Management	3.75	8	0.341	3.70	8	0.058	4.24	4	0.330	4.00	1	0.357	4.17	4	0.065	3.64	6	0.530	4.09	3	0.423
Project Procurement Management	3.98	5	0.632	3.93	5	0.708	3.26	10	0.581	3.27	10	0.800	3.54	7	0.110	3.93	5	0.816	3.30	9	0.800
Project Stakeholder Management	4.31	2	0.279	4.24	2	0.105	3.71	7	0.601	3.74	7	0.504	3.53	8	0.949	4.15	2	0.585	3.67	7	0.844
Mean	3.96	2		3.93	3		3.98	1		3.77	6		3.92	4		3.82	5		3.77	6	

M – Mean, R – Rank, MW – Mann Whitney U Test among Organization Sizes (SME vs Large Enterprise)
* Significant with p-value <0.05

5 Conclusions and Further Research

Smart technologies associated with the 4IR can overcome many of the challenges faced by industries. However, the fragmented nature of the construction industry leads to a general resistance toward change and laggardness in technology adoption. At the same time, this presents huge potential to overcome the specific challenges of the construction industry. To increase the adoption of smart technologies, this study examined the smart technologies with the greatest impact on project management, the impact of the smart technologies on project management knowledge areas and assessed if organizations of different sizes perceived the impact of smart technologies on project management differently. All smart technologies were found to impact all project management knowledge areas at varying degrees, with AV, robotics, CPS, IoT and BD perceived to have the greatest impact on project management knowledge areas. Organizations of different sizes also perceived differences in the impact of several smart technologies on project management knowledge areas.

While the objectives of this study have been achieved, there are some limitations to be considered. This study collected the perceived impact of smart technologies on project management, which may be subject to the respondents' past experiences. Next, the response rate is relatively low and more reliable results may be produced with a larger sample size. Despite the limitations, the findings serve as starting points for construction organizations to prepare for the digital transformation by anticipating the changes to project management processes. This may increase the adoption of smart technologies and ultimately improve the performance of the construction industry. Future studies can be conducted to investigate the specific changes to project management processes according to each application in the construction industry and on the specific competencies required to manage projects incorporated with smart technologies.

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ASSESSING IMPLEMENTATION OF PLANNING AND SCHEDULING IN CONSTRUCTION PROJECTS ACROSS INDIA

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Abstract
The Indian construction industry is estimated to contribute 9% to the country's GDP, and the industry is currently worth approximately US$ 145 billion. The market has shown excellent growth potential, but the industry is also facing delayed projects. 70% of infrastructure projects in India face time and cost delays which pose a significant risk to the stakeholders. The COVID-19 crisis worsened the situation as 90% of construction projects in India were slowed down due to the lockdown. Over 30% of labours stayed away from construction sites for fear of contracting the virus, leading to unprecedented circumstances. The leading causes of the delays identified in this research are unforeseen circumstances that remain unaccounted for during project planning and scheduling and a lack of clear communication between project stakeholders. This research focused on planning and scheduling challenges in four different construction terrains in India: hilly region, northern plains, coastal and desert region. The construction sites in these regions face distinct challenges like various soil types, variable climatic conditions, and challenging logistics. This paper highlights essential techniques of planning and scheduling, barriers, the importance of proper planning and scheduling and the significance of the role of the PM to improve the delivery of the projects.

The research would support the project stakeholders in understanding the importance of applying planning and scheduling techniques in the construction industry of India.

Keywords
Indian construction industry, planning, scheduling.

1 Introduction

The stakeholders, client, consultant, contractor, suppliers, and investors are crucial to driving a construction project and are responsible for optimizing construction project management due to the industry's competitiveness. Project management aims to effectively enhance the objectives according to the stakeholder's needs by proper planning and coordination. It involves a clear definition of the project scope, accurate cost estimates, resources allocation, and a strong understanding of project management to develop effective project planning and scheduling, enabling timely project delivery according to cost and quality objectives. Clients need to realize the returns on their investments, and thus, planning and scheduling perform an essential role in completing the project on time and at a predetermined cost. Construction planning is necessary and thought to provoke activity for managing and executing construction projects. Scheduling means creating order and logic for construction activities and estimating the workforce and other related resources for the project's construction. The main reason for poor project performance is the lack of knowledge of proper planning and scheduling techniques. Baldwin and Bordoli (2014) said that effective project management, project execution, and project planning and scheduling are the keys to success. This research focuses on the construction projects of India, where the projects are constantly being affected by schedule and cost overruns. Such problems are improper planning and scheduling of the construction activities and arise due to inappropriate explanations of the project scope of works during the initiation stage. These challenges can be overcome by clear communication between project stakeholders and keeping the variance of planning and scheduling to the bare minimum.

1.1. Research objectives

A successful project means completed within pre-planned time, quality and cost objectives; project delivery is according to the needs of the project stakeholders and completed within the defined scope (Kerzner, 2009). The reality is there are flaws in planning and scheduling, and these can arise due to improper identification of risks in the initial planning stages. Sometimes threats are unforeseen, like the recent COVID-19 virus, which has led to project delays worldwide. There is a need to account for good float between key project milestones during the project planning to have minimum impact on final project delivery. The research focuses on different topographies of India: Hilly Region (Himalayas), desert region (Thar desert), Coastal region (western and eastern ghats), and northern plains, each having unique construction practices, leading to the implementation of variable planning and scheduling techniques.

The literature reviewed construction projects in India, and the analysis has shown that most projects are being affected by time and cost overruns. It is unclear that the main reason behind the delay is poor planning and scheduling of activities. For example, analysis of Indian government infrastructure projects shows that only 20% of projects are on schedule, and 80% are suffering from either time or cost overrun (COVID-19: Assessment of economic impact on the construction sector in India, 2020). This report states the effect of COVID-19 is severe on the project cost as it has led to an increase in labour cost by 20%-25%. Megaprojects in India showed that 47% face delays due to multiple reasons (Singh, 2009). Government analysis shows that every project suffers from 20%-25% cost and time overruns (Ministry, 2021). According to the latest report published by MOSPI, examining over 1700 projects, 401 projects have cost overruns, 583 projects are facing schedule delays, and 205 projects have time and cost overrun (COVID-19: Assessment of economic impact on the construction sector in India, 2020). The main reasons for delays were land acquisition, inadequate planning and inappropriate budgeting, underestimation of project cost, changes in project scope and shortage of workforce (Ministry, 2021).

The aim is to inspect the significance of project stakeholders in understanding the application of planning and scheduling techniques in the construction industry of India.

The following defined objectives will achieve the aim:

- To identify various planning and scheduling techniques that are essential for proper project planning and scheduling.
- To recognize the barriers to planning and scheduling and defining the techniques to overcome these barriers.

- To highlight the importance of proper planning and scheduling in project management.
- To analyse the significance of project managers in the construction industry across India.

2 Literature Review

The Indian construction industry will grow at a CAGR of 15.9%. It is driven by commercial sector CAGR of 16%, followed by infrastructure sector CAGR of 13% and lastly driven by residential sector CAGR of 11.1% (Markets, 2021). The decline in the residential sector is due to the increase in unemployment due to COVID-19. The industry will rise due to the government's effort to develop the country's infrastructure and housing sector. There is tremendous growth in this industry, but the question arises: is this industry ready to acquire the benefits of the development. The weak points of this industry are less usage of technology and the absence of standards across the construction process. By adopting better practices like a shift to better work quality and less wastage, the organizations can capture this growth potential.

2.1 Topography of India

India has diverse topographies spread across all its regions, which influences adopting appropriate construction methodology. The various construction topographies in India are the hilly region, northern plains, coastal and desert region. Construction in these regions faces distinct challenges like a different type of soil, variable climatic conditions, unique building techniques, and logistics difficulties.

India's weather ranges from a temperate climate in the north to a tropical monsoon in south India. During March- June, there is summer, July- October is monsoon, and from November- February, there are winters (Asianinfo.org, n.d.). The terrain varies across India, i.e., flat planes along the Ganges, desert in the west, the Himalayas, the hilly region in the north, and coastal plains in the south. The typical hazards across India are floods, earthquakes, droughts, soil erosion, deforestation, air pollution, water pollution, and overpopulation. These regions possess variable risks to the planning and scheduling of construction projects.

2.2 Planning and Scheduling in Construction Projects

Construction project management aims to optimize the project's objectives effectively according to the stakeholder needs by proper planning, coordinating and controlling and enables project delivery within time and cost constraints. Poor project performance depends upon the improper application of project management concepts, leading to poor planning and eventually leading to project failure.

CIOB states that planning is "the determination and communication of a proposed course of action integrating thorough methods showing time, place and the resources" (CIOB, 2011).

Scheduling means creating an order, logic, and estimating workforce to build the most efficient and cost-effective project. Scheduling sets the thorough working plan on a time scale set by crucial objectives (Hildreth et al., 2005).

Baldwin and Bordoli (2014) have mentioned that sharing the construction plan among the project's stakeholders is mandatory, which are an essential part of the construction process, the clients, project managers, architects or designers and contractors.

E.g., Bandra- Worli sea link in Mumbai highlights the failure of a major project in India. The project was planned for US$ 45 million (INR300 crore) and is to be completed by 2004. Still, eventually, it was finished with a five-year delay in 2009, with an actual cost of US$237 million (Rs.1600 crores), which is approximately 425% cost overrun from the project estimated cost (Bharath and Pai, 2013).

2.2.1 Project stakeholders and their roles and behaviour in planning and scheduling

The flow of communication between project stakeholders is not given adequate importance during construction practice. Effective planning and scheduling of the project influences the organization's culture and mindset of the project team. The roles of project stakeholders for the progress and control of construction plans must be defined and synchronized for the successful completion of the project.

(Owolabi et al., 2014) observed that the client caused 51% of the delays, followed by the contractor at 36% and consultant at 13%. Industry research shows that based on the ratio of the final estimated cost to estimated cost, approximately 40% of all the projects undergo more than 10% change (Ibbs, 2012). As the number of changes increases, the project's productivity decreases, which leads to cost overruns and time delays.

It is essential to have detailed inputs from the project stakeholders in the early planning stages to implement project planning. Understanding scheduling concepts should include critical issues such as buffers, resource loading, identification of risk, and mitigation and control techniques (Heuer and Zack, 2014). Heuer and Zack (2014) also mention that scheduling ensures that all the activities to be performed by the contractor are adequately planned, coordinated, staffed, and executed sequentially. It also adds to the decision-making of the stakeholders regarding the monthly progress payment of the contractors. The owner and the contractor must agree upon a schedule that indicates a logical path for completing the project.

2.2.2 Methods & tools for project planning and scheduling

The Methods and tools utilized for construction planning and scheduling are Gantt charts, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Critical chain project management and Last Planner System. The Gantt chart is displayed with bar charts, emphasizing the percentage complete of each task without showing the links between them. Whereas PERT shows the interlinkage between the activities and highlights information as a network model, it does not show the percentage completion of tasks. PERT can help the project manager to visualize the sequence of activities (Bryant, 2007). Critical chain project management concentrates on the issues in scheduling activities and finds the crucial activities that form the 'critical chain' for construction work. The last planner system sees what 'should be done, considers what 'can' be done, and helps decide what 'will' be done.

2.2.3 Barriers to planning and scheduling

A proper definition of the project's scope at the initial planning stages is necessary for projects success. An unnecessary involvement by project stakeholders can hinder the success of the planning stage. Studies have highlighted that the delay in planning stages is because of the desires of the project stakeholders. Owners play a more significant role by constantly changing the scope of the project. An attitude of not focussing on project planning harms the projects' performance. Refer to figure 1 and 2 which highlights the common barriers to planning and scheduling.

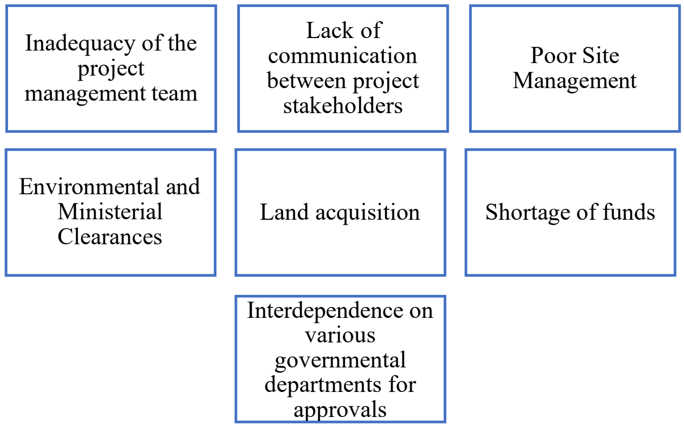

Figure 1 Barriers to project planning

Figure 2 Barriers to project scheduling

The project's success relies on the effectiveness of the planning stage, and adequate resource allocation leads to accurate planning. Planning further leads to scheduling which is responsible for the execution of the work, and proper scheduling helps the stakeholders monitor the progress of the project.
Stakeholders are the key decision-makers, and clear communication is essential for the project's success. The more integrated the stakeholders better will be the delivery of the project.
Planning depends on topographies, and different topographies have multiple challenges. It is comparatively easier to work in the resourceful cities, e.g., Delhi, Mumbai and Gujarat, compared to comparatively less resourceful hilly regions, e.g., Kullu, Shimla, Manali, Jammu & Kashmir. Extra precautions are needed while planning in topographically challenging areas.

3 Research Methodology

This research paper observes the understanding of the project stakeholders regarding planning and scheduling, emphasizing how they modify planning and scheduling due to the problems faced while working in different topographies of India. The research also highlights the difficulties encountered in other regions of India that hinder the construction process and understands the role of the project manager in managing the projects.

This research had adopted an interpretivism epistemology, a study in which the researcher must interacts with the research. Data was collected using both qualitative and quantitative approaches. The researcher conducted around 12 semi-structured interviews and 50 questionnaires across ten projects in different regions of India. The collected information is from project stakeholders: the client, project manager, contractor, and architect from the other areas of India, i.e., hilly region, desert region, the northern plains, and the coastal region. The connection between literature and research adopted deductive and inductive approaches. The deductive approach incorporates quantitative data and begins with theory and hypothesis, followed by research that validates the literature. The inductive study includes qualitative data, begins with real-life examples, and progresses towards literature based on the observations.

4 Findings and Discussion

4.1.Respondents Background

The data collected targets the viewpoint of the major project stakeholders: the project manager, client, contractor, and architect (refer to figure 3). The perspective of all stakeholders (refer to figure 4) is essential to understand as it assists in answering the objectives.

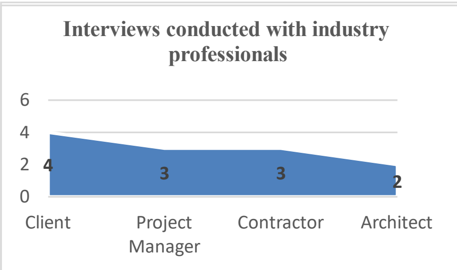

Figure 3 Interviews conducted with industry professionals

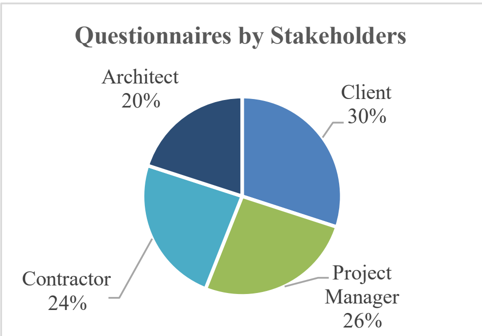

Figure 4 Questionnaires responses by industry professionals

This research has covered responses from industry experts with different years of experience to receive valuable project insights (refer to figure 5).

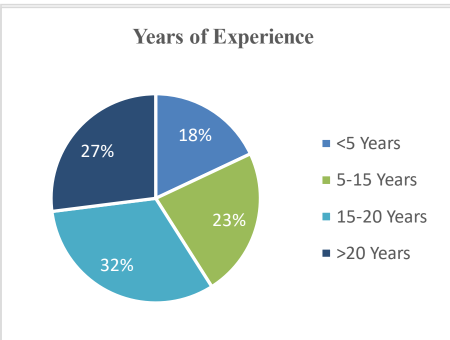

Figure 5 Respondents' Years of Experience

4.2.Data Analysis

The data was thoroughly collected across all the regions of India, and most people who responded possess an experience of over 15 years, which validates the quality of data utilized. The responses highlight both planning and scheduling have equal importance in the successful delivery of a project. The methods and tools of planning and scheduling used in different regions of India are similar, and the utilization varies based on the barriers each area possesses.

The key deliverables from this research are:

- Only 20% of the respondents feel that planning and scheduling have been ultimately adopted in the industry and the remaining are unsure about the implementation.
- 44% of the people feel that planning is vital for the execution of the work as, without a proper plan, there is no execution strategy to follow. The project managers use the project plan to decide the schedule of activities and inspect the quality of work.
- 52% of the respondents believe that scheduling is important as delays in scheduling can lead to project failure in terms of completion date. Scheduling is also used for resource planning, workforce management and procurement of construction materials.
- 64% of respondents believe that the role of the PM is essential for the execution of the work. The PM is responsible for monitoring the site and making crucial decisions regarding the implementation of the work. Whereas 40% of the respondents disagree that only the PM is responsible for the project's planning. The planning process is a team effort, and this has been stated and accepted by 50% of the respondents.
- Effective planning and scheduling barriers are budgets, natural calamities, change in the original scope, unskilled workforce, and the project budget. 40% of the respondents believe that the significant barriers are all the above, but 28% think there are other planning and scheduling barriers. These barriers are unavailability of resources, poor communication, improper project leadership and inefficient experience in planning and scheduling.
- A project can have multiple delays, and 64% of respondents believe that float in project scheduling is essential for delivering the project on time.
- 48% of the respondents believe that culture has an impact on construction projects. The Indian construction industry is multi-cultured with people from different caste and religions, following various rituals, and speaking other languages.
- 56% of the respondents mention that CPM is widely used, followed by PERT and Gantt chart. It is vital to be on schedule with activities on the critical path as a slight deviation could lead to an overall project delay by two months or more, as stated by an interviewer.

4.2.1. Region-based analysis

Hilly Region: Planning and scheduling are essential in this region. Proper planning leads to accurate scheduling and thus fewer delays. Critical path and PERT are the techniques that are used for planning and scheduling. The activities on the critical path are not delayed, as they can lead to the overall delay of the project. The barriers in this region are unwanted rainfall, high-risk work environment, work casualties leading to a loss time incident, and restricted use of heavy vehicles. These barriers can be overcome by considering these factors during the formation of the project baseline.

Desert Region: Proper planning and scheduling are critical for the success of the project. The critical path method is the commonly used technique in this region. A milestone chart is prepared to monitor the success of the project. The barriers in this region are extreme weather conditions, lack of resources and unskilled labour. These can be mitigated by localizing procurement, hiring skilled labour and resources from nearby areas, and distorting the working hours for the execution of work.

Northern Plains: It is the most accessible terrain to work, and planning and scheduling play a significant role in project success. CPM, PERT and Gantt charts are the techniques that are used in this region. The water level is low, hence adequate government clearances are required, the laws are relatively strict in this region, and there might be a hindrance from government and political parties. Overcoming barriers through adequate consideration of obstacles during the planning and proper communication between the project stakeholders.

Coastal Plain: In this region, excessive rainfall can affect scheduling as it leads to floods. Bribing officials to get work done is a common practice, and it involves enormous risk, and RTI activists also pose a threat to the construction activities. Strip and pile foundation is used in this region as the bearing capacity of the soil is low.

In general, festivals affect the scheduling of activities in all the regions of India. The diverse culture of this industry plays a significant role in managing the construction project.

Planning and scheduling are crucial in executing and monitoring construction activities (refer to figure 6).

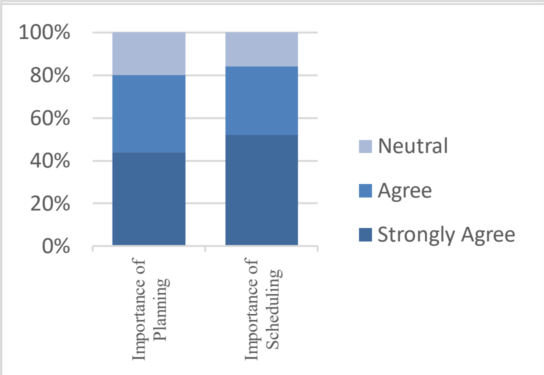

Figure 6 Importance of Planning and Scheduling

The project manager plays a significant role in the execution of construction projects. The project manager acts as the project owner on the site and makes crucial decisions to complete the project. The questionnaire has determined 64% of the respondents believe the role of the project manager is significant in the execution of the construction project. It has been illustrated below in figure 7.

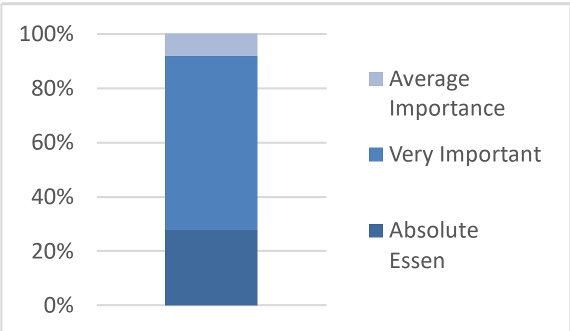

Figure 7 Importance of the role of PM in managing construction projects

The common barriers to planning and scheduling were defined by the respondents, as illustrated in figure 8.

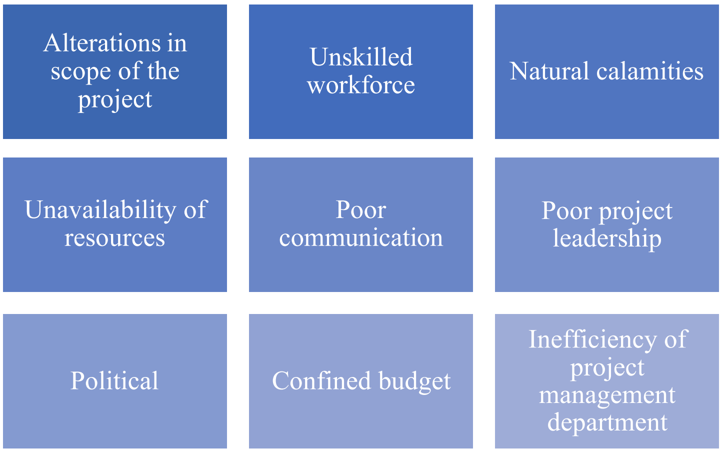

Figure 8 Barriers to planning and scheduling

Figure 9 illustrates the commonly used project management techniques mentioned by the respondents through the questionnaire.

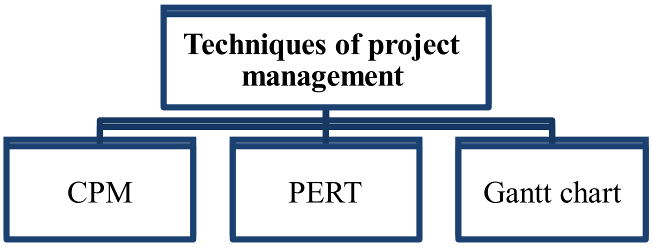

Figure 9 Techniques of project management

5 Conclusions and Further Research

The research objectives are evaluated based on the literature review and the data collected through interviews and questionnaires.

The study concludes that all project stakeholders play a crucial role in determining the project's success and are equally vital for the proper execution of the construction activities. Each region of India faces barriers that can be mitigated by proper planning and scheduling. Still, construction is most challenging in the hilly area, followed by the desert region, and it is most feasible in the northern plains. The challenges can be overcome by clearly defining scope, detailed resource allocation, localized procurement, and proper communication. The respondents had variable opinions on the correct planning and scheduling technique but emphasized that technique changes as per the nature of the project. The responses were in cohesion with the literature that planning, and scheduling are crucial for successfully delivering a construction project. At the same time, it highlights that both these activities are a team effort that involves all stakeholders. The research emphasizes the project manager is responsible for the on-site execution of the work, and the effectiveness of the project manager depends upon the proactiveness of the client and other stakeholders. The manager drives the project through the knowledge and experience essential for constructing projects in any environment. This research has aimed to inspect the significance of project stakeholders in understanding the application of planning and scheduling techniques in the construction industry of India.

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Logistics strategy, structure, and performance: A typology of logistics configurations in construction

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Abstract

Building contractors need to understand their operational context to manage logistics efficiently and effectively. However, we know little about the choices regarding organization of logistics in building contractors and its relationship to performance. Thus, the purpose of this paper is to develop a typology of ideal logistics configurations and to discuss the strengths and weaknesses of the fit as profile deviation perspective for logistics configuration studies in construction. The typology is based on a critical review of stand-alone contingency studies within the logistics and construction management research domains. Two logistics configurations positioned at the extremes of a spectrum are identified. The first is the product-process oriented configuration resembling to the way industrialized housebuilders organize and manage logistics. The second is the project-oriented configuration, which resemble to how logistics is managed when operations are characterized by a high degree of on-site construction and project-specific engineering designs. The product-process oriented configuration typically generates low total costs of material supply and short and reliable lead times, while the project-oriented configuration has a flexible material supply process to support the high degree of variability in on-site operations and in the supply chain. Thus, these two configurations will perform better within different performance categories (project lead time, cost, and flexibility). Furthermore, the fit as profile deviation perspective is a promising approach to empirically assess the two configurations. For managerial practice, the typology can guide building contractors and consultants in evaluating existing logistics configurations and how to maintain ideal configurations when new logistics roles emerge.

Keywords

Building Contractors, Configuration Research, Logistics Strategy

1 Introduction

During the last decade, new specialized logistics-related roles have emerged in construction companies. The new roles include logistics managers, coordinators, and specialists that are responsible for setting up the site layout, managing the material flow process, delivery planning, materials handling on-site, etc. (Dubois *et al.* 2019). Previous studies indicate that the organization of logistics, including these new roles, influence the performance of construction projects. For instance, on-site productivity is positively affected by specialization of logistics tasks (Sundquist *et al.* 2018) and companies can achieve economies of scale by using joint logistics resources across several projects (Dubois *et al.* 2019). Thus, the matter of how to organize logistics tasks has become increasingly important at the strategic level of building contractors.

Building contractors are a diverse group which consist of large general contractors, industrialized housebuilders, residential builders, etc. (Simu and Lidelöw 2019). Therefore, to manage logistics efficiently (i.e., achieve intended logistics outputs) and effectively (i.e., to achieve intended performance outcomes), contractors need to understand their type of operations and how it influences organization of logistics. The role of logistics differs across the spectrum of production systems, which in turn requires contractors to organize and manage logistics in a way that it supports their operations (Klaas and Delfmann 2005). Yet, so far, most research on organization of logistics in construction has focused on adapting logistics principles to construction with limited consideration of building contractors' operational characteristics.

Contingency theory is a common approach to organization of logistics, which contends that an alignment between the context and organization structure lead to better performance. However, logistics researchers have argued that contingency factors provide only a partial explanation to the strategy-structure-performance links (Klaas and Delfmann 2005). Configuration theory suggests an alternative approach and combines an array of contingency variables derived from stand-alone logistics contingency studies. This is a holistic approach that account for the strategy-structure-performance relationships more comprehensively than individual contingency studies do (Ketchen Jr *et al.* 1993). When applied to logistics, configuration theory suggests that a high degree of fit between several logistics context and organization structure variables should lead to certain performance outcomes (Klaas and Delfmann 2005; Pfohl and Zöllner 1997).

The challenge in studying logistics configurations comes from the plethora of analysis methods resulting from different perspectives to the fit of a sample configuration profile. Each perspective thus have different implications for how to approach, interpret, and empirically evaluate the effects of configurations on performance outcomes. Venkatraman (1989) proposes six different perspectives that form the basis for configuration studies that focus on the fit between constitutive elements: *fit as moderation*, *fit as mediation*, *fit as profile deviation*, *fit as gestalts*, *fit as covariation*, and *fit as matching*. Each of these perspectives differ in scope of and level of detail, which means that the perspective that is selected need to suit the phenomena being studied. The most common perspective for studying the effects of a configuration's fit on performance is from the perspective of fit as profile deviation. Here, fit indicates an adherence to a sample configuration of an ideal configuration. In other words, a deviation from the ideal profile is negatively related to performance, while exhibiting a high degree of fit to an ideal profile is positively related to performance. Thus, the purpose of this paper is to develop a typology of ideal logistics configurations in construction and discuss the strengths and weaknesses as to how fit as profile deviation can be used to study the relationship between logistics configurations and performance in construction.

2 Logistics Configurations

Configuration theory postulates relationships between strategy, structure, and performance, which require consideration of multiple interrelated variables. Central to the configurations approach to logistics is the concept of fit between two groups of variables: the *logistics context* and the *organization of logistics* (Klaas and Delfmann 2005). Furthermore, it requires consideration of two elements: verbal statements (i.e., conceptual definitions) and operationalization of its constructs that enable empirical analysis (Venkatraman 1989). Both these two elements are necessary in theory building research using the configurations approach. The former ensures that the constituents of a particular configuration are rigorously defined, and the latter is the means needed to measure the constructs (Wacker 1998). Drawing on previous configuration studies and stand-alone contingency studies, the following sub-sections focus on defining conceptual definitions of logistics context and organization variables.

2.1 Logistics Context

Logistics literature provides a plethora of logistics context variables, such as strategy, environmental uncertainty and heterogeneity, importance of logistics, and information technology (Chow *et al.* 1995). However, Sousa and Voss (2008) argue that contingency based studies must identify a limited set of variables that best account for different contexts. Many logistics context variables proposed by logistics researchers have several resembling labels and conceptualizations and there are no general exact definitions. This partly stems from the broad range of fields in which they have been applied. Thus, it is necessary to define domain-specific logistics context variables for construction. As such, based on previous work on logistics-related contingency research in manufacturing (e.g., Chow *et al.* (1995), Pfohl and Zöllner (1997), Klaas and Delfmann (2005)) and construction (e.g., Jonsson and Rudberg (2015)), the logistics context of building contractors can be reduced to two variables. The first context variable is *the degree of pre-engineering* to account for the product-related contingency effects. The second is *the degree of off-site assembly* and addresses what typically is considered as process choice or technology in the manufacturing industry.

The reason for choosing the degree of pre-engineering is that it captures the product characteristics that differentiate between different housebuilders. In general, product characteristics is a broad concept that subsumes several other underlying concepts, such as product design, value density, product range, bill of materials (BOM) structure, etc. (Pfohl and Zöllner 1997). Housebuilding is engineer-to-order (ETO) production and thus, production is entirely order-driven with inventories consisting of only raw materials and components, if any (Johnsson 2013). As such, the degree of pre-engineering provides a useful distinction between different ETO situations and denotes to what extent the building specifications can be adapted according to client input (Schoenwitz *et al.* 2012). In other words, the degree of pre-engineering accounts for the extent to which design and engineering activities are performed prior to the customer-order decoupling point (CODP) (Wikner and Rudberg 2005). Table 1 describes the three groups of ETO products that represent different degrees of pre-engineering.

Table 1. Degrees of Pre-Engineering in Housebuilding (based on Wikner and Rudberg 2005; Jonsson and Rudberg 2015).

Pre-engineering	Value adding prior to CODP	Product Standardization	Customizable BOM levels	Client input
Design-to-Order (DTO)	None	Pure customization	6<	High choice of building design
Adapt-to-Order (ATO)	Standard parts, components, and sub-assemblies	Customized or tailored standardization	3-6	Limited choice of predetermined options
Engineer-to-Stock (ETS)	Standard buildings or building modules	Segmented or pure standardization	0-2	Limited/no choice of building design

For process choice, the *degree of off-site assembly* represents different production processes in housebuilding. Process choice has been rigorously defined in operations strategy literature via the product-process matrix (Hayes and Wheelwright 1979). Jonsson and Rudberg (2015) proposes a product-process matrix for the housebuilding context comprising of two dimensions: the degree of product standardization and degree of off-site assembly. The degree of off-site assembly is used to denote to which extent a building is prefabricated in an off-site factory. Production is still driven by customer orders, but building components and modules are produce in a controlled environment and assembled on site. However, an off-site factory is typically feasible when is combined with relatively high degree of standardization to reach sufficiently high production volumes (Gibb and Isack 2003; Jonsson and Rudberg 2014). The feasible degree of off-site assembly thereby corresponds to the degree of pre-engineering; as customization increases, more production activities become feasible to perform at the construction site. Table 2 describes four generic production systems in housebuilding.

Table 2. Process Choices in Housebuilding (based on Gibb and Isack 2003; Jonsson and Rudberg 2015).

Process Choice	Prefabrication	Site Assembly
Component Manufacture & Sub-Assembly (CM&SA)	Raw materials/components	Entire building
Prefabrication & Sub-Assembly (PF&SA)	Panel elements	Windows, doors, façade, non-load carrying elements
Prefabrication & Pre-Assembly (PF&PA)	Panel elements with pre-assemblies	Non-load carrying elements
Modular Building (MB)	Volumetric modules	Volume module assembly

2.2 Organization of Logistics

While logistics context variables lack consensus in literature, organizational variables are more consistent across domains. Nonetheless, there are some contingency variables that are unique to logistics, besides those commonly used in contingency studies, such as centralization and formalization (Meyer *et al.* 1993). Table 3 presents the five variables for organization of logistics identified in this study with their respective conceptual definition.

Table 3. Conceptual Definitions of Organization of Logistics Variables.

Variable	Conceptual Definition	Key Authors
Formal Structure	The degree to which logistics decision-making is concentrated to a single unit and their proximity to top management.	Chow *et al.* (1995), Pfohl and Zöllner (1997), Moretto *et al.* (2020)
Integration	The degree to which logistics tasks are coordinated with other functional areas within the firm.	Chow *et al.* (1995)
Supply Chain Structure	Geographic dispersion of suppliers, distribution network, and construction sites. Channel governance in terms of vertical integration and supplier relationships.	Klaas and Delfmann (2005), Voordijk *et al.* (2006), Hofman *et al.* (2009), Stock *et al.* (2000)
Division of Labour	The degree of specialization in physical (transportation, material handling, goods reception) and administrative (order processing, delivery planning, inventory management) logistics tasks.	Dubois *et al.* (2019), Klaas and Delfmann (2005), Lindén and Josephson (2013)
Formalization	The degree to which logistics processes, policies, procedures, and strategy are documented.	Chow *et al.* (1995)

Formal structure indicates the degree to which logistics tasks are concentrated to a single unit and the proximity of this unit to top management within the organization (Chow *et al.* 1995). Typically, this is referred to as the degree of centralization in the (logistics) organization structure. As centralization in logistics tasks increases, it typically follows a reduction in its ability to handle variation at the operational (project) level (Pfohl and Zöllner 1997). Centralization reduces the organization's information processing capabilities and when paired with production task variability, it creates a misfit between the information processing requirement and capacity (Galbraith 1974; Luo and Donaldson 2013). For instance, when purchasing and material flow processes are aggregated at the company level which limits the ability to cope with rush orders and changes in production schedules (Moretto *et al.* 2020). Furthermore, a high degree of centralization in the formal structure tends to be followed by a high degree of integration between different functional departments (Chow *et al.* 1995).

The supply chain structure constitutes of two elements and denotes the physical arrangement and governance structure of supply chain members (Klaas and Delfmann 2005). The physical element specifies the geographical dispersion of production facilities, suppliers, and customers (Stock *et al.* 2000). The governance structure indicates the buyer-supplier relationship, which subsequently is characterized by two dimensions: 1) the degree of vertical integration and 2) the strength of relationships between supply chain members (Voordijk *et al.* 2006). Based on the two dimensions, the governance structure can vary from integrated hierarchical structures with close buyer-supplier relationships to disintegrated market structures with loose buyer-supplier relationships. Furthermore, a third mode of channel governance, the network structure, is positioned between markets and hierarchies. The network structure denotes vertically disintegrated organizations but with close buyer-supplier relationships (Stock *et al.* 2000). These buyer-supplier relationships can be either short-term (project) or a long-term (strategic supplier) depending on the type of building material supplier (Voordijk *et al.* 2006).

The division of labour denotes the specialization in administrative and physical logistics tasks (Klaas and Delfmann 2005). An example of specialization in administrative logistics tasks is the use of logistics specialists in projects that have taken over material flow-related tasks from site management (e.g., site layout planning, delivery planning, etc.) (Dubois *et al.* 2019). Physical task specialization is typically achieved by purchasing carry-in services from a third party (Lindén and Josephson 2013). Furthermore, formalization is typically coupled with specialized and indicates to what extent decisions, tasks, and supplier relationships are governed by formalized processes, rules, and operating procedures (Chow *et al.* 1995).

3 Defining Fit - A Typology of Ideal Logistics Configurations

Fit is the common denominator that enables a distinction between different configurations. According to configuration theory, a fit between the individual variables correspond to a certain configuration where different compositions of variables form configurations with distinctive characteristics (Meyer *et al.* 1993; Venkatraman 1989). Configurations can be either conceptually or empirically derived, i.e., defined with typologies or taxonomies respectively. However, Meyer *et al.* (1993) view the dichotomy of typology and taxonomy-based configurations as artificial. Typologies are based on synthesis of stand-alone empirically driven contingency studies. On the other hand, all taxonomies are theoretically based since the forming of empirically driven configurations rely on organization theory. Thus, they should be viewed as complementary when describing configurations and it is instead the replicability of a configuration that is important (Miller 1996). Typology and taxonomy-based configurations do however require different methodological approaches. For instance, taxonomies can require cluster analysis to identify the configurations while typology-based configurations are identified through conceptual modelling (Venkatraman 1989).

Logistics configurations are typically typology-based, i.e., they synthesize stand-alone logistics contingency studies (Klaas and Delfmann 2005). This enables formation of configurations that represent a fit between a set of multiple interrelated logistics context and organization variables. In construction, two distinctive configurations have emerged via the distinction between *product-process oriented* firms and *project-oriented* firms (Lessing *et al.* 2015; Simu and Lidelöw 2019). Although these types of contractors are not the outcome of explicit configurations studies, their definitions closely resemble to that of the logistics context in logistics configuration research (c.f., Chow *et al.* 1995; Klaas and Delfmann 2005; Pfohl and Zöllner 1997). Therefore, two logistics configurations can be distinguished via their process choice and product characteristics. The product-process oriented configuration are typically industrialized housebuilders that produce highly standardized products via a high degree of off-site assembly. On the other hand, the project-oriented configuration tends to produce highly customized products via a low degree of off-site assembly (Jonsson and Rudberg 2015).

Based the contextual and structural differences between product-process and project-oriented configurations, they produce distinctive logistics outputs and subsequently produce different performance outcomes (Klaas and Delfmann 2005). Here, it is important to note that the strategy-structure-performance links in configurations studies differs from that of bivariate contingency studies. In configurational studies, it is the fit between multiple interrelated variables that relate to certain performance outcomes. Hence, the performance outcomes are a result of adhering to an ideal configuration profile rather than the features of individual constructs, such as centralization and formalization (Venkatraman 1989). This indicates that different compositions of multiple interrelated contextual and organizational variables will result in different logistics outputs. Figure 1 builds on the logic established by Vorhies and Morgan (2003) and illustrates the postulated relationships between logistics configuration profile fit, logistics outputs, and performance outcomes. For each ideal type of logistics configuration, there are certain logistics outputs that are specific for the type of configuration (Klaas and Delfmann 2005; Pfohl and Zöllner 1997).

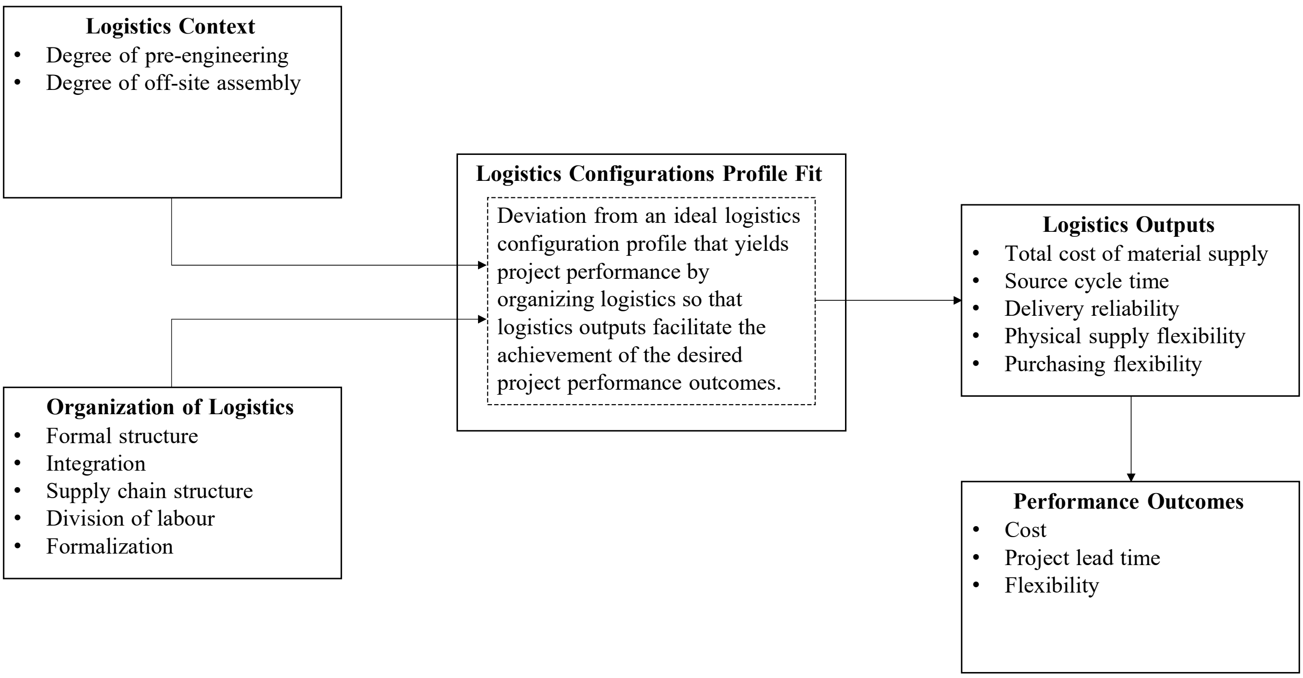

Figure 1. Logistics configuration profile fit, logistics outputs, and performance outcomes.

3.1 The Product-Process Oriented Configuration

Product-process oriented firms typically strive for low project costs and short project lead times combined with a high delivery precision by specializing in producing residential buildings for a narrow target market in an off-site factory (Jonsson and Rudberg 2015). The logistics context is thus characterized by a high degree of off-site assembly (MB) and a high degree of pre-engineering (ETS). This configuration's organization of logistics is characterized by centralization in logistics tasks. Centralized planning and control are typically feasible when there are only a few organizations' material and information flows that need to be coordinated (Rudberg and Olhager 2003). Product-process oriented firms can thus have formal operating procedures which are performed by a specialized planning function that coordinate material and information flows to and between multiple projects (Dubois *et al.* 2019). The supply chain structure that is characterized by geographical concentration, tight buyer-supplier relationships, and a high degree of vertical integration (Voordijk *et al.* 2006). Consequently, most value-adding is concentrated in an off-site factory with central inventories of finished volume modules and direct distribution to the construction site. This enables the product-process oriented firm to pursue a push-logic in inbound and production logistics in the off-site factory and thus optimization of both order-sizes of material components, production lot-sizes, and inventory of finished volume modules. However, final assembly still takes place at geographically dispersed locations. Hence, the material flows from the off-site factory to the construction site follow a pull-logic which needs to be synchronized with off-site factory takt time and volume module deliveries (Arashpour *et al.* 2017).

The logistics outputs of this configuration are mainly cost and lead time related. Centralized planning and control of material and information flows with formalized procedures enable contractors that adopt this configuration to exploit company-wide resources better than project-oriented configurations (Dubois *et al.* 2019). Furthermore, a centralized supply organization that engage in long-term relationships with material suppliers for standardized components facilitate short sourcing cycle times, high delivery reliability, and low administrative and physical distribution costs (Bildsten 2014).

3.2 The Project-Oriented Configuration

The project-oriented configuration can typically not match product-process oriented configuration's performance in terms of project lead time and cost level but strive to deliver a wider range of projects according to different customer requirements (Jonsson and Rudberg 2015). Due to the small production volumes of each product variant and variations in the production process, the formal structure of the logistics organization is typically decentralized with less formalization and specialization than the product-process oriented configuration (Klaas and Delfmann 2005). The project-oriented configuration's supply chain is highly dispersed since the suppliers differ from project to project and are typically procured locally. Logistic tasks are decentralized and instead there is a reliance on the project organization to coordinate material flows in individual project's supply chains (Simu and Lidelöw 2019). This gives rise to a high number of converging material flows to the construction site which leads to a temporary and geographically dispersed supply chain. As such, logistics integration is limited to activities and firms within the project, which restricts cross-functional integration at the company level.

The low degree of centralization, specialization, and formalization facilitates logistics flexibility, which is the ability of logistics system to manage both anticipated and unexpected in material supply that require rapid changes in the logistics system (Jafari 2015; Sandberg 2021; Zhang *et al.* 2005). Zhang *et al.* (2005) points out four elements of logistics flexibility, of which two are relevant to building contractors: 1) physical supply flexibility indicates that material deliveries and inbound supply resources can be adjusted in response to production requirements, and 2) purchasing flexibility denotes the ability to source different materials and components in different batch sizes on a short notice. A project-oriented configuration is thus characterized by a high degree of logistics flexibility, but it comes with precondition that flexibility does not entail a relatively large increase in total costs.

4 Findings and Discussion

The product-process and project-oriented configurations identified in this study represent the two extremes in the typology, and there is potential to identify further configurations that are positioned in between (see e.g., Jonsson and Rudberg 2015). Most configuration studies are however taxonomy-based and combine cluster analysis to derive ideal configurations empirically with profile deviation to compare the degree of fit in the sample to that of the ideal configuration (e.g., Kristensen and Nielsen 2020; Tomas *et al.* 2007; Vorhies and Morgan 2003). It is generally more difficult to define ideal profiles in typology-based configuration studies as the ideal configuration needs to be theoretically derived (Venkatraman 1989). On the other hand, Ketchen Jr *et al.* (1993) argue that taxonomy-based configurations provide little ground for studying the configuration – performance relationship and are better suited for describing configurations per se. The typology-based approach is however the more feasible alternative when the aim is to analyze the relationship between logistics configurations, their respective logistics outputs, and performance outcomes.

The typology and taxonomy-based approaches does however share the problem of being cross-sectional and only providing a static perspective to configurations. This is a potential issue for research on logistics configurations within construction since cross-sectional configuration studies can produce conflicting results (Venkatraman 1989). Logistics management in construction is still regarded as immature (Janné and Rudberg 2020) albeit the developments during the recent decade. A cross-sectional logistics configuration study in the construction domain may therefore risk of being overly conservative (particularly taxonomy-based studies) or idealistic (particularly typology-based studies). Additionally, the concept of fit is in its infancy in construction compared to manufacturing, which may indicate that fit is not a conscious choice among building contractors. For researchers, it is thus important to determine what constitutes fit in an ideal logistics configuration profile. This calls for both taxonomy and typology-based approaches as they are mutually reinforcing in the theory-building process (Ketchen Jr *et al.* 1993; Meyer *et al.* 1993; Venkatraman 1989).

Cross-sectional approaches are most likely the most feasible approach regardless of them being empirically or theoretically based. However, as new construction logistics practices, roles, actors, and organizations evolve, dynamic approaches will be needed to capture what is happening beyond the cross-sectional configuration samples (Venkatraman 1989). A potential venue for studies adopting the dynamic approach is to apply organizational information processing theory. Longitudinal studies can reveal how construction companies manage mismatches between organizational processing requirements and capacity over time (Galbraith 1974; Luo and Donaldson 2013). This has the potential to inform both theory and practice in terms of the process of arriving at fit.

5 Conclusions and Further Research

The purpose of this paper was to develop formal conceptual definitions of the constitutive elements of logistics configurations in building contractor firms and to define what characterizes ideal logistics configurations. The two logistics context variables and five organizational variables defined in this paper provided the basis for a typology of ideal logistics configurations in construction: the product-process oriented configuration and project-oriented configuration. This typology can be used to study determine the respective strengths and weaknesses of different logistics configurations in and their logistics outputs and performance outcomes. Fit as profile deviation is regarded a suitable analysis method to take in consideration both the configuration's profile deviation from that of an ideal configuration, and its effect on logistics outputs and subsequent performance outcomes. Taxonomy-based configurations are more suitable whenever there is uncertainty of what characterizes an ideal configuration and when the configuration – performance relationship is beyond the scope of the inquiry. This is due to the lower degree of generalizability among taxonomies, which limits them in comparing performance across different configurations. For managerial practice, the typology can guide building contractors and consultants in evaluating their existing logistics configurations and how to maintain ideal configurations when new logistics roles emerge.

The main limitation of this study is that it remains to empirically test the typology presented in this study. As such, empirical investigations can reveal the configurations positioned in between the two extremes to capture the entire spectrum of logistics configurations. Lastly, configurations can be studied at different points in time and levels of analyses. This study focused on the individual building contractor's configuration, but future studies can pursue longitudinal research designs and attempt to identify logistics configurations at the project/programme level through a multi-stakeholder perspective.

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Client Involvement and Construction Project Healthy and Safety Performance

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Abstract
Despite significant effort by business associations, researchers, construction clients and contractors to deal with the unsatisfactory health and safety (H&S) performance in the construction industry, the situation has not improved. Lack of effective involvement by clients has contributed to the construction industry's extremely high number of accidents that occur on a daily basis, resulting in medical treatment cases, lost time incidents, fatalities and damage to property. The objective of this study was to investigate clients attitude towards project healthy and safety performance and the extent to which South African construction clients are involved in projects. A questionnaire was designed for respondents to assess the extent to which construction clients were involved in construction project health and safety in projects they had managed and to evaluate the health and safety performance of those projects. Results from data collected across 135 large-size construction projects in South Africa were analysed using descriptive statistics. Results showed that the attitudes of clients and their involvement before and during construction was unsatisfactory. The results of the study confirmed that involvement by clients throughout the phases of the project could lead to improvement in project health and safety. Future studies should be conducted using a larger sample size to improve the application of the model in the construction industry.

Keywords

construction clients, construction health and safety, health and safety performance, project performance

1 Introduction

The construction industry is one of the sectors that creates the most employment opportunities for unskilled and semi-skilled workers from impoverished local communities due to its relatively labour-intensive nature (Phoya, 2012 ; Musonda, Pretorius and Haupt, 2012). Regardless of its important role and contribution to economic growth, the construction industry remains a risky sector where the most vulnerable (unskilled and semi-skilled) workers are continually involved in serious construction accidents. Although there have been interventions by various stakeholders to deal with this problem, the results remain unacceptable as accidents continue to persist in the construction industry.

Although several programmes have been implemented by government authorities and other relevant stakeholders to improve the standard of health and safety (H&S) at construction project sites, the construction industry in South Africa still has an unacceptably high level of incident rates. This causes extensive human suffering – and despite measures introduced by the contractors themselves, construction workers continue to be fatally injured and exposed to occupational health hazards (Lopes, Haupt and Fester, 2011; Umar, Egbu, Honnurvali, Saïdani and Al-Bayati, 2019).

Despite significant efforts by industry associations, researchers, construction clients and contractors to improve H&S in the construction industry, overall construction H&S performance has not improved and continues to contribute an unacceptably high level of injuries and fatalities. The construction industry continually fails to comply with construction regulations (CR 2014) in South Africa. To address the unacceptably high level of incident rates in the construction industry, many countries have developed laws and regulations that govern the processes in which construction clients must manage H&S on construction sites.

Client influence in construction projects has been cited by numerous researchers as a lasting solution for reducing the number of H&S accidents on sites (Smallwood,2004 ;Votano and Sunindijo, 2004 ; Kikwasi, 2008) . There is a legal and moral responsibility on owners to ensure that their contractors comply with H&S requirements (Huang, 2003). From the construction process perspective, there are three key issues that affect the project owner (The Hartford Loss Control Department, 2002) namely, moral obligation, legal obligation and potential cost savings. In terms moral obligation, employers are generally expected to provide and maintain a safe working environment that is without risk to the health of employees. This moral obligation goes beyond the employees of contractors and includes other stakeholders. In terms of legal obligation employers have a duty to inform and warn their employees, contractors and other stakeholders about any potential hazardous situation on sites. The clients could be held liable for injuries to any of the project stakeholders caused by their failure to enforce strict H&S requirements on a site that is under their control. In terms of potential cost savings, any effort shown by clients for H&S on site has the potential to bring down construction costs as the number of injuries reduce (Chunxianga,2012).

Jazayeri and Dadi (2017) revealed that various researchers have conducted studies in the construction industry on client influence on construction project H&S performance, identifying factors causing poor performance in construction projects and critical success factors influencing safe programme implementation. Musonda, Pretorius and Haupt (2012) investigated the influence of clients on construction project H&S performance in Botswana and South Africa, and that H&S performance was better when factors associated with client health and safety culture were observed. Musonda et al., (2012) argued that in most instances the role of construction clients is ignored by researchers as they place most of the emphasis on contractors. A study by Huang and Hinze (2006) found that H&S performance is improved when construction clients strictly enforce H&S compliance for contractors. Liu, Jazayeri and Dadi (2017) conducted a study to evaluate the degree to which owners are involved in site safety issues. They developed a model – Owner's Role Rating Model (ORRM) – to test the extent to which construction clients participate in health and safety and presented a survey instrument to assess the level of participation by owners in site safety management. Liu et al., (2017) conducted an evaluation of twenty projects by using ORRM to verify its applicability in the construction environment; the study concluded that owners with little involvement in construction projects could use the ORRM to identify the critical points for better performance.

Although there is consensus amongst researchers that client participation throughout the phases of construction projects can lead to improvements in the H&S performance of these projects, very few studies have explored this area in the South African context. Lack of effective participation of clients in health and safety has left the construction industry with a very high number of accidents every day, resulting in medical treatment cases, lost time incidents, fatalities and damage to property that occur on construction sites.

This study aims to assist clients to influence contractors in improving the health and safety performance of construction projects effectively.

2 Research Methodology

A quantitative research method was adopted for the study. For the purpose of this study, the target population includes construction clients of building, housing, civil construction, petrochemicals, roads and earthworks, and structural, mechanical, electrical, instrumentation, piping and platework (SMEIPP). The data was gathered directly from clients, professionals representing client health and safety agents, construction managers, construction health and safety managers and officers. A total of 135 projects, with a value of more than R40 million, were targeted for this study. The study was limited to construction projects that started during the period 2014 – 2017 and excluded projects that involve maintenance work.

Descriptive statistics were used to provide an analysis of measures of central tendency. In ensuring that the data is useable, reliable and valid for testing causal theory, the data was screened for any irregularity using SPSS for outliers, extreme values, missing data and disengaged responses before subjecting them to exploratory factor analysis (EFA) to assess the factor structure and reliability and validity of the measures. Exploratory Factor Analysis was used for data reduction and to examine the factor structure of the measurement instrument using SPSS.

3 Data Analysis

3.1 Response Rate

Construction projects (150) with a value of more than R40 million were included in this study. The survey was administered through a combination of emails and follow-up calls. The data was gathered directly from clients, professionals representing client health and safety agents, construction managers, construction health and safety managers and construction health and safety officers. By the cut-off date of the survey, 135 usable responses were received. This represented an approximate ninety per cent usable response rate, with most responses (thirty-four per cent) from building (commercial) projects being the highest.

3.2 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) was used to test the reliability and validity of the variables assessed in the study. The EFA aims to reduce data by finding the smallest manageable set of common components that will account for the intercorrelations of a set of variables (Pallant, 2011). The steps involved in the EFA include assessment of the suitability of the data for factor analysis, determining numbers for factor extraction, retaining and rotation, interpretation of resulting factors. The analysis included the evaluation of reliability (Cronbach alpha and composite), and discriminate and convergent validity of the survey instrument. To assess the suitability of the respondent data for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (MSA) and Bartlett's test of sphericity were used. Latihan et al., (2017) described KMO MSA as a test of the extent of variance within the data that could be explained by factors. Latihan et al., (2017) stated that as a measure of factorability, a KMO value of 0.5 is poor, 0.6 is acceptable while a value closer to one is better. Neuman (2003) and Tabachnick and Fidell, (2008) suggested that KMO measure of sampling adequacy must be 0.7 and 0.60 respectively. For this present study, the KMO MSA was 0.771, suggesting that the sample size is adequate for EFA.

The Bartlett's test of sphericity needs to be significant for the sample to be deemed to have sufficient variance for EFA. Peri (2012) suggested that for factor analysis to be recommended suitable, the Bartlett's test of sphericity must be less than 0.05. Taking a ninety-five per cent level of significance, $\alpha = 0.05$ and the p-value (Sig.) of .000 < 0.05, shows that the factor analysis was valid.

3.3 Multivariate Analysis Assessing Client Attitude Towards Health and Safety

Using a Five-point Likert Scale, where 1= Never and 5=Always, respondents were required to evaluate a set of questions pertaining to their attitude towards health and safety performance of their construction projects. The assessment of questions revealed low mean scores ranging from 2.76 to 1.85, indicating that the respondents had a poor attitude towards health and safety on their projects.

Table 1. Client involvement in health and health and safety before construction

	Mean	SD
Does the client address health and safety issues in the feasibility study and conceptual design phases?	2.76	1.63
Does the client require designers to consider construction health and safety during constructability/buildability reviews?	2.40	1.54
Does the client conduct a review of the design for health and safety?	2.33	0.73
Does the client prefer to award the contract to a design- build contractor to promote health and safety performance?	2.33	1.82
Does the client conduct the preconstruction meeting with contractor for health and safety issues?	1.90	1.43
Does the client require designers to conduct a review of the design for construction health and safety for this project?	1.85	0.77

3.4 Multivariate Analysis Assessing Client Involvement in Construction Health and Safety

Using a Five-point Likert Scale, where 1= Never and 5=Always, respondents were required to evaluate a set of questions pertaining to their involvement in health and safety performance of their construction projects. The results from Table 2 show mean scores ranging from 3.22 to 1.43. The understanding of clients contribution to health and safety performance (mean score= 3.22) was ranked highest.

Table 2. Client involvement in health and health and safety before construction

	Mean	SD
Does the client understand that their involvement contributes to health and safety performance?	3.22	0.95
Does the client set zero harm, injury or incidents as the objectives for the project?	3.16	0.97
Does the client go beyond a regulatory compliance approach to prevent injuries or incidents?	2.54	1.36

Does the client through include all requisite information such as outcomes of baseline H&S hazard identification and risk assessment (HIRA) in the form of H&S specifications as part of tender documentation?	2.20	1.64
Does the client have specific health and safety goals for each project?	1.43	1.25

4 Findings and Discussion

Liu (2017) pointed out that there are many activities before construction commences that could affect the health and safety performance. Huang (2003) stated that owners could impact designers and contractors through their proactive participation in construction safety issues. In South Africa, the Construction Regulation (CR) 2014 imposes a clear obligation to clients to provide the designers with the health and safety specification and ensure that designers consider safety specification during the design stage. The results from the questionnaire survey show that client involvement in H&S before construction is not common in the South African construction industry. Respondents indicated that clients are not consistent with the legal obligation of being involved before construction. Further, it was found that there was almost no client involvement in H&S before construction of the projects. The fact that the client is rarely involved in health and safety before and during construction in the industry is a cause for concern.

The results from the questionnaire show that the client attitude towards H&S was perceived to be negative in the construction industry. Respondents indicated that the client attitude towards H&S was not consistent in the construction industry. This means that these clients never show commitment to H&S. The client attitude towards health and safety starts with their understanding that their involvement could contribute to project health and safety performance. According to Musonda et al., (2009), client attitude can be explained by the extent of the client involvement in the management of H&S. This could be achieved by the clients setting zero harm, injury or incidents as the objectives for the project. Liu (2017) stated that the client attitude towards H&S determines the effort the client is willing to make towards ensuring that H&S is not compromised on project sites. One of the efforts the client could make is to go beyond a regulatory compliance approach to prevent injuries or incidents on site.

5 Conclusions and Further Study

The study reported on the extent to which clients attitudes towards health and safety performance in construction projects in South Africa. More specifically, the involvement of clients in the practice of health safety on their projects. Findings from the survey were that construction client attitude towards H&S is critical to the performance of all stakeholders in the projects. The study further revealed that once the construction client sets the H&S tone then their attitude can exert a great influence not only on the performance of H&S but also on other project Key Performance Indicators (KPIs). Unfortunately some construction clients still leave the H&S issue to the contractors. The finding that most construction clients are not involved with H&S before the project is a cause for concern especially since the construction client is legally required to provide the designer with the health and safety specifications contemplated and ensure that the designer takes the prepared health and safety specification into consideration. Consequently, an appropriate intervention in terms of policies, procedures and active monitoring could be formulated that seek to enforce construction client compliance to H&S legal requirements.

Finally, given that the sample was limited to 135 large construction projects, a larger sample size could have benefited considering the importance of this study. The survey indicator variables may be refined to suit specific project environments.

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Track 7

Integration of Data and Information

BIM-based LCA Integration by Evaluating the Environmental Impacts of Whole Building at the Early Design Stage

Business Models for Smart BE

Perspective of Public-Private Partnership (PPP) in Various Economies

Automation and Robotics

Using Artificial Intelligence to Automate the Quantity Take-off Process

Paradigm Shift of Claims Management to Digital Space

The impact on Culture of Smart BE

Construction and its Delivery of Social Capital: An Investigation of the Impact on Culture, Heritage and Wellbeing of Minority Ethnic Communities in Malaysia

BIM-Based LCA Integration by Evaluating The Environmental Impacts of Whole Building At The Early Design Stage

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Abstract: Recently, environmental Life Cycle Assessment (LCA) has become an impartible part of many building projects. There is greater need to integrate LCA tools with the building design workflow. There are several LCA tools, where some of them use an internal database and some are open source platforms that better enable the use of wide-array of database sources as their life cycle inventory. The former tools have limitations in their database coverage while the latter mostly use the datasets that are not specified for construction projects. This study aims to support the design of resource- and energy-efficient buildings using an integrated LCA methodology in the early design stage. The research aims to integrate LCA capabilities directly into a Building Information Model (BIM) and increase the environmental relevance and scientific robustness of LCA indicators. The plugin, which is developed in the BIM tool is represented to use Ecoinvent to build a complete process of a construction projects to be imported in OpenLCA. The results show much efficiency in using the developed plugin to assist users to find the correct materials from database within the seconds as well as a clear framework that helps to map all the processes of LCA without faults or forgotten processes.

Keywords: Life Cycle Assessment (LCA), Building Information Modeling (BIM), Environmental impacts, Embodied Carbon, Building Performance.

1 INTRODUCTION

It is recognized that climate change is now a major problem facing humanity (Huisingh et al., 2015). Governments around the world have struggled to balance economic growth with its negative effects on the environment, in both the developed and developing world. Buildings, through their construction, operation and eventual demolition, and currently this is associated with large emissions of fossil carbon (Alwan et al., 2015). Sustainable development is a more established concept with a much larger scope compared to that of climate change. It is generally acknowledged that sustainable development can be achieved through balancing the three bottom lines (TBL): society, the environment and the economy (Kang, 2015). Buildings consume energy and contribute to GHG emissions both directly and indirectly throughout their life cycle phases. Direct energy use and emissions are related to the processes of construction, operation, renovation and demolition, whereas indirect energy consumption and associated emissions are caused by production and transportation of materials, as well as technical installations (Huang et al., 2017).

The building and construction industry has been driven to adopt green building strategies in light of increasing sustainability concerns such as reducing CO2 emission and energy dependency on fossil fuels (Lu et al., 2017). As a revolutionary technology and process, Building Information Modeling (BIM) has been regarded by many as a significant opportunity in the architecture, engineering and construction (AEC) industry. BIM emerged as a solution to facilitate the integration and management of information throughout the building life cycle (Wong & Zhou, 2015). There are several tools and methods to help the implementation of sustainable development into the built environment (Alwan et al., 2015; Kang, 2015).

Life cycle assessment (LCA) is a powerful tool to help sustainable design move towards a performance basis. An analytical method for estimating lifetime environmental impacts due to a product or process, LCA can help building designers quantify and validate their sustainability decisions. LCA quantifies the resource consumption and emissions due to constructing, using and disposing of a building, and then estimates the resulting impacts to the environment (O'Connor and Bowick, 2014).

LCA is a useful tool for estimating the cradle-to-grave (i.e. life cycle) impacts of a building. Despite the goal of LCA in evaluating key requirements of sustainability in the building construction industry, there are different challenges facing the application of LCA. Examples of these challenges are the potential changes in the form and function of buildings during the entire service life which typically spans more than 50 years, the challenges of forecasting the whole life cycle and reducing the environmental loads of buildings (Khasreen et al., 2009).

The objectives of this study are to follow the modelling principles of LCA in an integrated and dynamic system to the design environment and to increase the robustness and realism in the environmental evaluation of buildings by integrating BIM principals with embodied carbon impacts analysis through LCA. The focus in this study is to support the design of resource- and energy-efficient buildings using a sound BIM and LCA methodology in the preliminary design stage. A procedure that can be implemented in day-to-day engineering practice for a detailed understanding of building performance is presented. The novelty of the work proposed here is to integrate operational energy analysis in an LCA approach for buildings. The proposed methodology is applied to an archetype office building as a case study project to prepare the integrated BIM-LCA environment to quantify operational and embodied impacts. The case study results and discussion are followed, and finally, concluding remarks are provided.

2 Literature Review

There are various studies about the potential of BIM- LCA integration towards the reduction of environmental impacts in the building sector. Ajayi et al. (2015) recognized the complexity and time-consuming nature of compiling input data during the LCI, and they also pointed out that it limits LCA application in the building sector. They recognized the effect of material specification on the life cycle environmental impact of buildings with the aid of BIM-enhanced LCA methodology. The development of the physical model provides manageable elements by designers from the early stages of design that are defined in the BIM modeling. In that sense, the level of development of the physical model (BIM modeling) defines the level of detail that will be developed through the LCA application. Their developed model was based on a LOD 200 model to obtain the approximate quantities, size, shape, location, and orientation that were required for both energy analysis and quantitative estimates. They have assumed a school building as the functional unit to develop the LCA and they developed a comparative analysis of environmental impacts including all life cycle stages. However, recycling and reuse potential stages were not included in the case studies. They carried out a method combining Revit, GBS, Microsoft Excel spreadsheets and the ATHENA Impact Estimator. While some studies use generic databases, they used regional databases. They used Autodesk Revit to develop the BIM model and then used an Excel spreadsheet to determine the materials that contributed to each of the components (Ajayi et al., 2015).

Kreiner et al. (2015) developed a methodology for building environmental assessment based on LCA, acknowledged the integration of LCA in BIM as a way of improving sustainability performance of buildings. Ilhan and Yaman (2016) presented a framework for this integration in order to build environmental assessment processes in the BIM platform, which would help the provision of documentation for green building certification. The authors state that the shifting approach to the building design, construction and maintenance needs an interdisciplinary collaboration. BIM for integrated sustainable design would simplify the certification process in terms of time and cost due to early stage interactions. Oti et al. (2016) mentioned that integrating sustainability decision modelling into BIM is still at the initial stage.

Despite the fact that the integration of BIM-LCA can reduce time and improve the application environmental performance of buildings from the early stages of design, certain methodological challenges are detected in theoretical terms (Soust-Verdaguer et al., 2017). Several papers which analyzed the integration from a methodological point of view highlighted the software integration as one of the most important challenges (Antón & Díaz, 2014). They assumed that a separate software solution connected to BIM would be easy to implement and user-friendly. Jalaei and Jrade (2014) evaluated and compared the capabilities of different file formats in transferring information from a BIM tool into energy analysis and simulation applications.

Mohammad Najjar et al. (2017) analyzed the methodology of LCA from a building perspective and presented the role of BIM and LCA integration in evaluating the environmental impacts of building materials in order to enable both the decision-making process and sustainable design procedure in the construction sector. The objective of their work was to motivate the integration of BIM and LCA methodologies in an initial design phase and to present the ability of such integration in evaluating the environmental impacts of construction materials. They have used Autodesk Revit as a BIM program and Green Building Studio and Tally applications in Revit as tools to achieve the objectives. Their work provides a practical application of BIM-LCA integration and analyzed the environmental impacts of building materials in the construction sector. They have applied the methodological framework of LCA based on ISO 14040 and 14044 guidelines, taking into consideration the basic steps of LCA methodology.

Although there are several recent works which performed BIM-LCA integration, one gap in the field of BIM and LCA integration lies in the insufficient methodological details to define the framework of BIM and LCA systematically to support the decision-making process in the construction sector and to protect the built environment (Najjar et al., 2017). Rúben Santos and António Aguiar Costa (2016) used a pilot case study in their research, aiming to recognise the influence of designers' decisions on the environmental impact of the building when comparing the environmental impact and energy consumption of a multi-family house with a single family house. As such, the Autodesk Revit was used to build the BIM model, Revit Energy Analysis for energy analysis and Tally for environmental assessment of the buildings. Despite recognizing Revit elements present in the project, the LCA plug-in used in their research did not recognize the objects' information, as it interacted with GaBi's databases. (GaBi, 2019).

3 METHODOLOGY

3.1 Framework and system boundary

The proposed model aims to automate the evaluation of life cycle assessment of a building project from a cradle-to-grave perspective. An integrated BIM-LCA methodology is proposed as the main strategy. Currently, there are several software to conduct LCA and each of them support their own database. The important point is that a precise LCA evaluation depends on the database, impact assessment and a correct model of inputs and outputs. For the first part, the ecoinvent v3.3 database (Ecoinvent 3.3, 2016) was selected as the main database and openLCA 1.9 (Greendelta, 2019) was selected as the engine for LCA calculations.

A plugin was developed to connect BIM software (i.e. Autodesk Revit) to the ecoinvent database which encompasses the integration point between bill of materials and life cycle inventory model for undertaking LCA in the openLCA software. To develop a correct input-output model, first a framework must be developed that contains four main phases of building material production, construction, use (operation and maintenance) and end of life in an LCA model of a project based on EN 15804 (BRE, 2013). System boundaries were defined to determine the inputs and outputs in each life cycle phase. The developed framework and system boundaries considered in this study are shown in figure 1 where the product phase follows the definitions that are defined in ISO 15804 (i.e. raw material supply, transport and manufacturing). In the construction stage, there is a construction process phase, which has been divided into three part of construction activities (i.e. excavation of footing), machine operations at construction site such as tower cranes and related labor-hour work requirements for each sub-task. In the use stage, building element-specific replacement requirements are considered and the inputs from the repair and refurbishment are not included due to lack of information. Demolition activities involving the disposal of materials as well as the transportation of disposed materials off-site were also included in the LCI model. The methodology automates the integration process between the BOM and LCI requirements by customizing and using the application programming interface (API) of a BIM tool (Revit) to enable users to connect their design with different modules instantly from within the BIM tool environment.

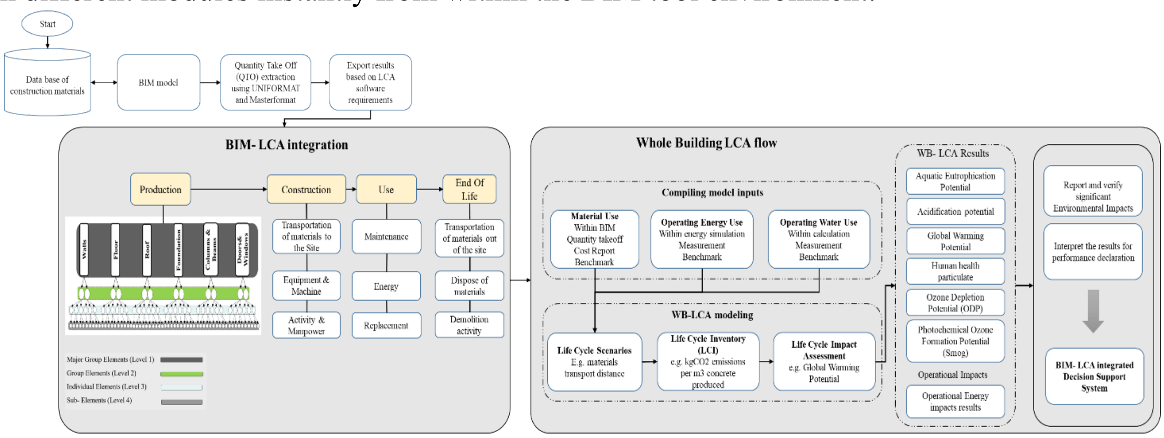

Fig.1. the integrated BIM-LCA model architecture

4 Case study

A sample study of LCA analysis using BIM is done on a 2-story clinic office building in city of Toronto with a total gross area of 1005.35 m2 and 781.91 m2 net conditioned area. Table 1 shows the specifications of the case project as well as the construction type information. The cooling system for the office building is assumed to be electric input ratio (EIR) chiller. The chiller component can be selected at the building level when the main HVAC system type is Variable Air Volume (VAV) or if one or more zone in the model has a fan coil unit. A hot water boiler is used as the heating system for the natural gas scenario. The power is generated in hot water by boiler systems. The generated heat passes through radiators or other devices in rooms throughout the building. To be reheated, the cooler water is required to be returned to the boiler. Generally, natural gas or heating oil is used by boilers. Boilers also use pump in order to circulate hot water through pipes to radiators. An electric heating coil is assumed as a heating system for the electric only scenario of the office building. A coil is a heating device that is connected to the heater itself which transfers the electric energy into heat energy. The heater generates the electric current that flows into the coil.

Table 1: Description of the Case example clinic office building

HVAC*: Heating, ventilation, and air conditioning, VAV*: Variable Air Volume, IEAD*: Insulation Entirely Above Deck.

Office building characteristics	
Parameter	value
Total Building Area [m2]	1005.35
Net Conditioned Building Area [m2]	781.91
Unconditioned Building Area [m2]	223.44
Gross Roof Area [m2]	537.38
Window Opening Area [m2]	102.41
Gross Window-Wall Ratio [%]	17.76
HVAC Air Loops [count]	4
Conditioned Zones [count]	36
Unconditioned Zones [count]	21
Air Terminal	Single Duct: VAV: No Reheat
ZONE HVAC	Baseboard connective electric
Air Loop HVAC	Thermo pump
Electricity + Gas Scenario	Heating: Boiler: Hot Water
	Cooling: Electric EIR chiller
Electricity only Scenario	Heating: Electric heating coil
	Cooling: Electric EIR chiller
Construction information ASHRAE 90.1-2010 exterior wall steel frame ASHRAE 90.1-2010 exterior roof IEAD Exterior slab carpet 8in 189.1-2009 exterior window	

90.1-2010 exterior window metal 189.1-2009 Non-residential skylight without Curb 189.1-2009 exterior door

4.1 Model implementation

Two Input Data Files (IDF) were developed for the office building: one representing natural gas heating and another representing electricity-based heating. These IDF files were based on the American Standard Code for Information Interchange (ASCII) standard (EnergyPlus 9.2, 2019), which contain the data describing the building and HVAC system to be simulated. One issue with the current energy simulation tools, which have the capability to create IDF files is that they do not have the capability of reading the weather (i.e. epw) files based on the projected data. Some tools have an integrated weather files into the software that could not be modified by user to import the customized projected weather data. Among these tools, Honeybee (Honeybee, 2019) is selected, which is a free and open source plugin to connect design tools such as Revit and Grasshopper3D to EnergyPlus, Radiance, Daysim and OpenStudio for building energy and daylighting simulation.

Honeybee is one of the most comprehensive plugins presently available for environmental design since it serves as an object-oriented API for these engines. It accomplishes the energy analysis task by linking the EnergyPlus simulation engine to CAD and visual scripting interfaces of Dynamo/Revit plugins, which is considered to be an ideal parametric tool for this research in order to create IDF files in an integrated BIM-based environment based on the projected weather files. Figure 2 shows the snapshots on the workflow which has been done in the Honeybee tool for creating an accurate building energy model. The zones are defined based on the clinic office usage then the custom loads are assigned, and schedules are set. By assigning the interior zones as well as the openings, the construction specifications are assigned based on the details explained in table 1. The HVAC system is defined for each building design scenario. The customized projected weather files (.epw) were imported to the energy plus panel. As illustrated in figure 2, by defining the file name and by switching the boolean toggle to true, the writing IDF process is started.

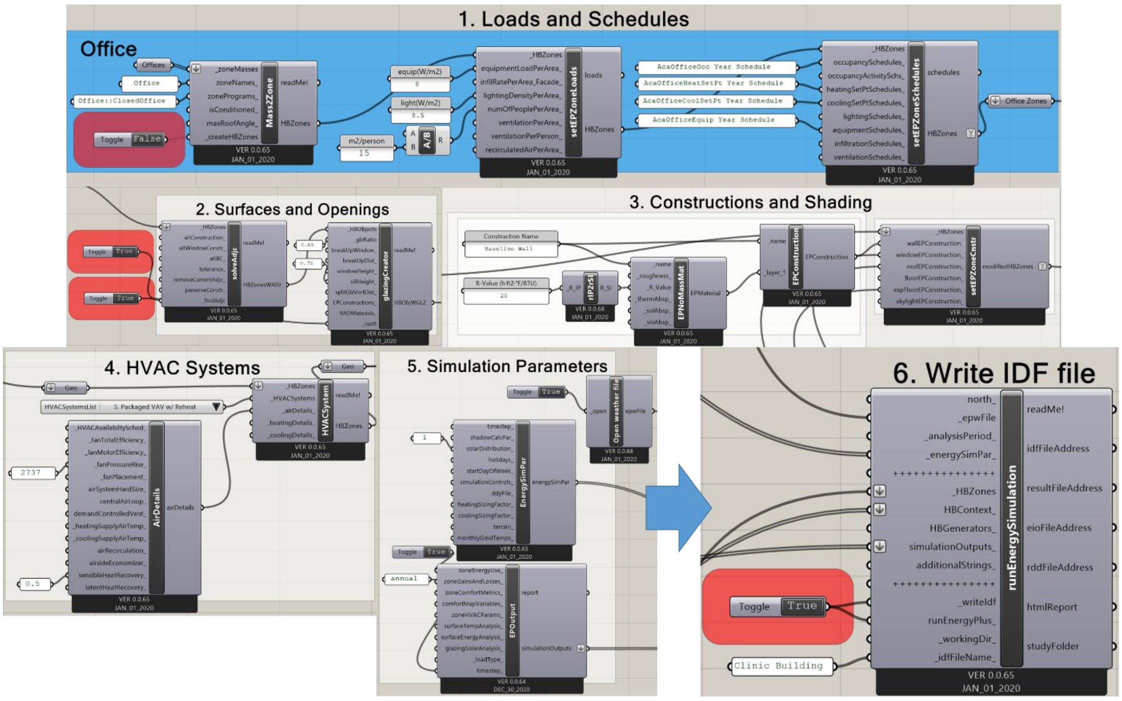

Fig.2. the process of creating IDF files in Honeybee for the office building based on the electricity mix scenarios

4.2 Calculation of operational impacts

The whole building energy simulation program utilized was EnergyPlus (EnergyPlus 9.2, 2019) , as it is a widely used program that engineers, architects, and researchers use to model both energy consumption— for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.

The environmental impact assessment model to calculate the life cycle environmental impacts was based on the TRACI method (LCIA methods, 2015), which is commonly used for North America.

In the developed BIM-LCA plug-in, as shown in figure 3, through selecting the building lifespan to be 60 years as well accounting for regional specifications, key building attributes were specified. The production stage includes the data mapping between the materials quantity take-offs extracted from the BIM model with the inventory list where the ecoinvent v3.3 database was used in a Revit plugin. The plug-in shows all the extracted materials in a hierarchical format (see figure 3). Therefore, the user can track and manage data mapping to ensure all the materials used in the project have been modeled and considered in the LCA. By selecting each item, the list of all relevant gate-to-gate processes in ecoinvent are shown and the user selects the most appropriate products/activities. To save time, the ecoinvent database is pre-filtered in the plug-in which enables a short list of appropriate materials/activities for the user to select from. The plugin takes the quantify take off from the BIM model and indicates the mapped items with colour coding (mapped items in green, incomplete mapping in yellow, not mapped items in gray).

For the construction phase the plugin offers three tabs where first all the materials used and associated transportation requirements across each building element were specified. The distance between manufacturing (or regional storage) and construction site can be automatically calculated by area code (e.g. zip code) via a google map feature. In this study the distance of 100 km was assumed for the transportation. The building construction process includes the quantification of installation and excavation energy and the amount of building material waste generated on site. The next tab is related to the machines and equipment used in the construction projects (e.g. hydraulic loader or crane). Since construction equipment are used on an hourly basis, they are assigned to the whole building process. The construction design and excavation activities require both fossil fuels and electricity. Due to a lack of specific case study data, mean electricity and diesel values required for construction of 60 MJ and 15 MJ per m2 of building area, respectively (Rezaei et al., 2019) were utilized. Wasted material generation were considered based on common waste factors (Athena, 2019) of the structural materials (i.e. concrete, steel, gypsum etc.) which are assumed to be transported to a waste sorting facility with an assumed distance of 100 km.

Embodied impacts also occur during the use phase of the building due to replacement and maintenance of building elements during the whole building life cycle. Material replacement is included in the maintenance phase on the basis of each material's service life. The list of elements that are extracted from the BIM model are displayed in the plugin and the user can define element-wise life expectancies. In this study default life expectancies (usage) for each building element were assumed (Athena, 2019). For the clinic building, painting was assumed to be performed every 5 years and doors, windows and curtain walls were assumed to be replaced every 20 years while the insulation and structural components were assumed to remain for the entire life cycle of the building.

The end of life stage includes an activity section similar to construction stage. The electricity at the demolition stage is the fossil fuel needed to power the deconstruction machines in the building. The end user can also select whether each building element should be disposed or recycled and thus link to an appropriate ecoinvent activity. The material disposal stage is modeled based on the building assembly classification (UNIformat). The demolished material was assumed to be transported from the building site to a landfill or waste sorting facility, and in this study, a distance of 100 km distance was assumed.

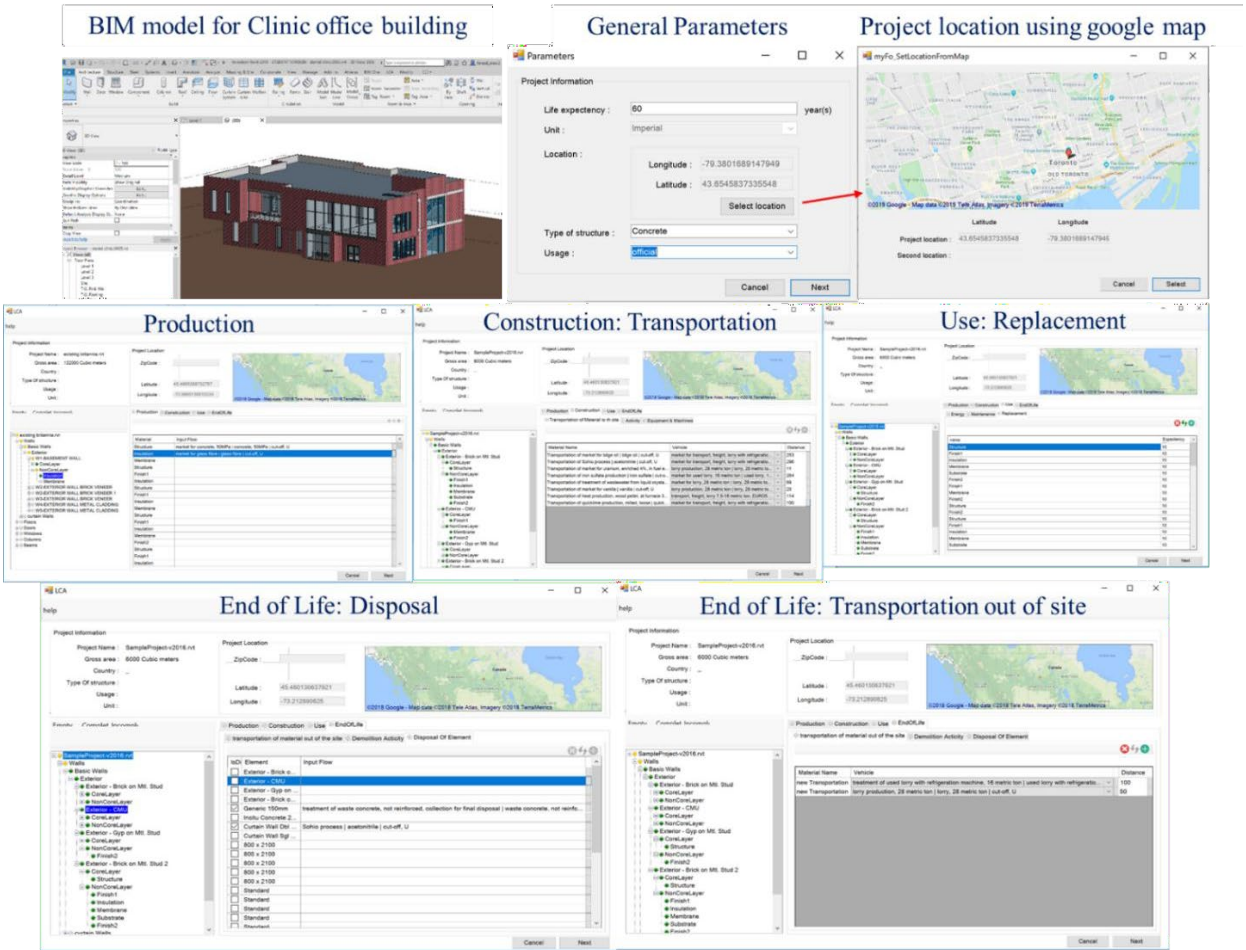

Fig.3. The process of linking material quantity take-offs with the LCI database using the BIM-LCA Revit plug-in

The output of the plug-in results in a JSON file equivalent to the OpenLCA schema (Greendelta, 2019) which is then imported into the OpenLCA software where LCA calculations can be performed. Based on the TRACI environmental impact method, the LCA calculations were performed where Monte Carlo-based uncertainty analysis with 5000 iterations was also undertaken.

Figure 4 shows the deterministic contribution percentages of embodied carbon based on the sub-categories of the clinic building life cycle (i.e. production, construction, replacement and end of life) as well as the normalized GWP impacts per square meter of conditioned area. As it is demonstrated, production has the highest share in the embodied impacts followed by the replacing the building components at the use stage. Floors and walls showed the largest percentage in GWP impacts at the production stage around 16% and 13%, respectively.

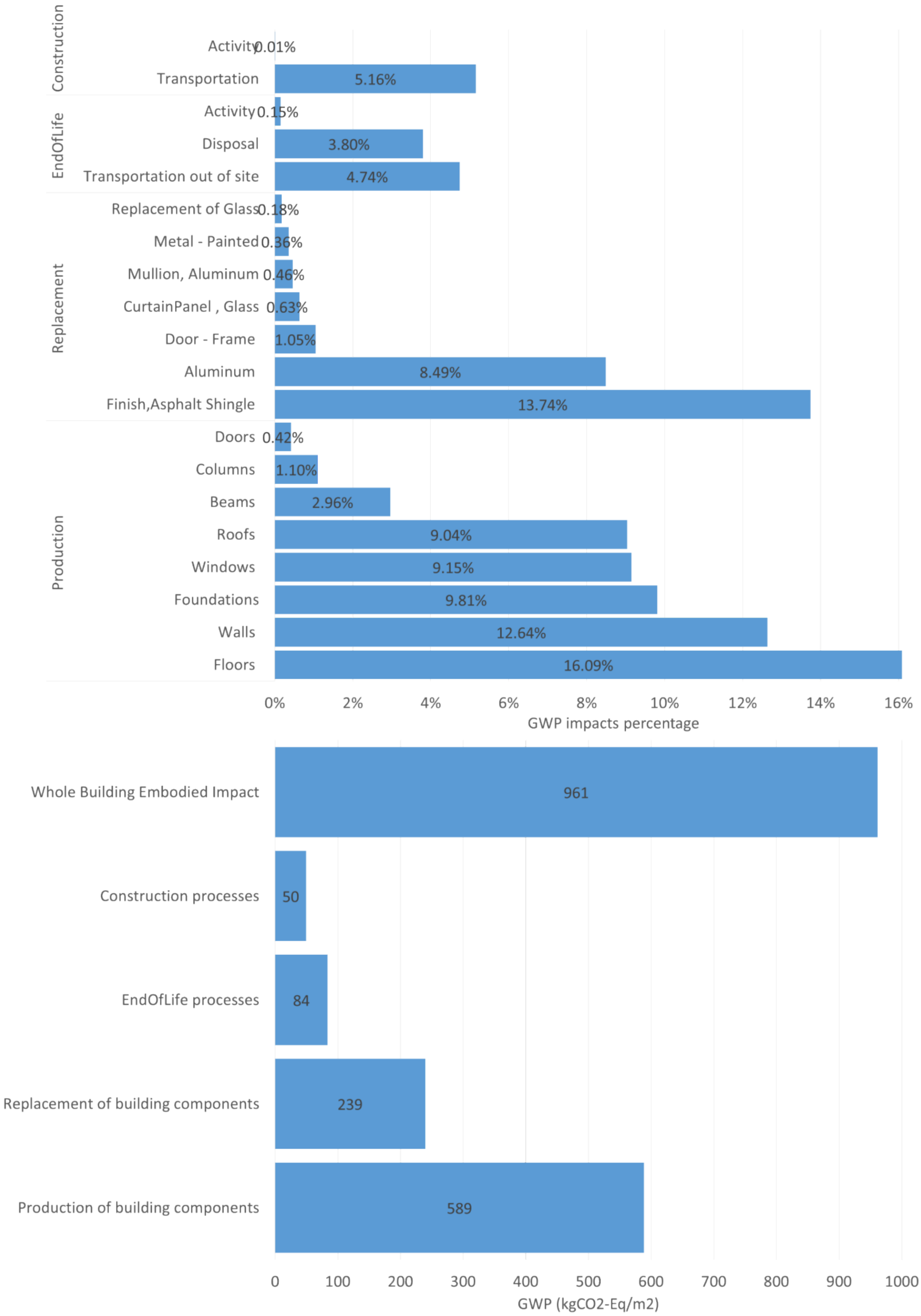

Fig.4. Global Warming Potential (GWP) embodied impacts contribution tree for the office building

These results are compared and validated with the embodied impacts benchmarking study (CLF, 2017), which evaluates the embodied GWP per square meter of building area based on the S=Structure, SF=Structure/Foundation, SFE=Structure/Foundation/Enclosure and SFEI=Structure/Foundation/Enclosure/Interiors for almost 1000 buildings, as shown in figure 8. By assuming the conditioned area of the building (781.91 m2), the embodied carbon for the studied office building resulted in 898 kgCO2eq/m2, which is in an acceptable area for SFEI benchmark. Figure 5 also illustrates the Monte-Carlo analysis results for about 5000 runs of the embodied carbon analysis through OpenLCA. Although the gross floor area is a common functional unit, but it is preferable to use net floor area as a functional unit because it is describing space that can be occupied for the operational purposes of the building. Using the net floor area was therefore the approach used here.

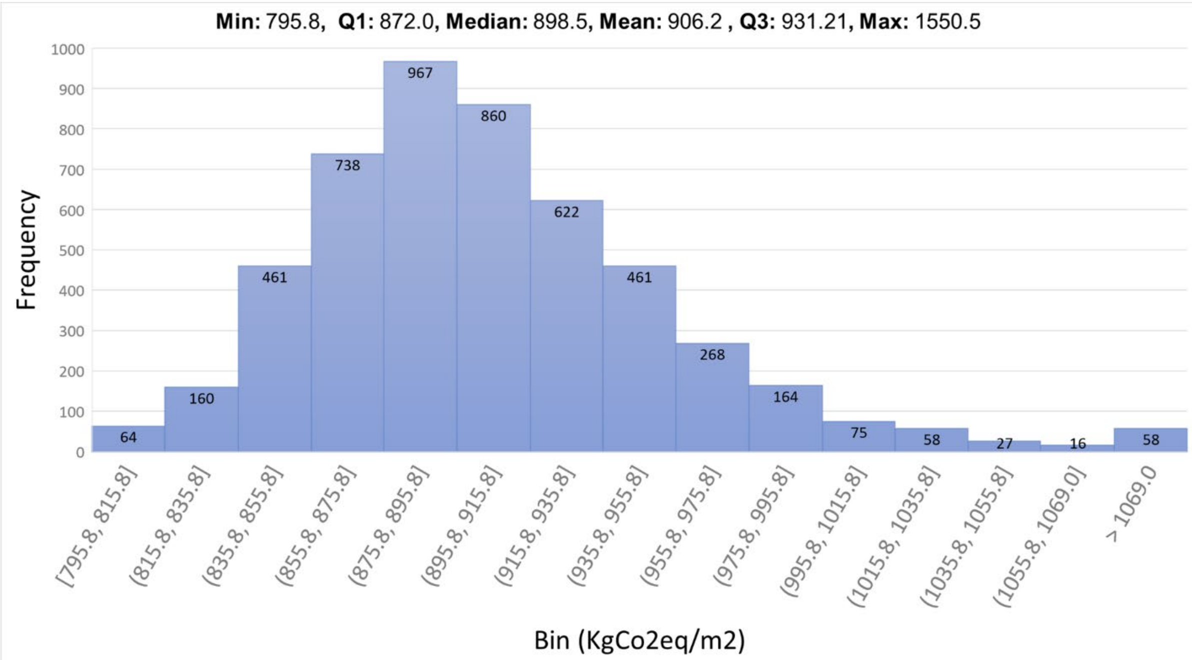

Fig.5. the Mont-Carlo analysis results for the embodied carbon for the clinic office building (5000 runs)

Figure 6 shows the whole-building GWP results where both the operational and embodied impacts are presented for the office building. The result is represented in kg CO2eq/m2 for both the natural gas and electricity heating alternatives. The evaluation results are clearly favourable for electricity-based heating for the office. The proposed approach would assist the design team to evaluate building environmental performance during its lifecycle in more accurate, close to realistic and more efficient way (less total GWP impacts). Therefore, the electricity-based space and water heating is recommended as a climate friendlier HVAC system for the case study office building in Ontario.

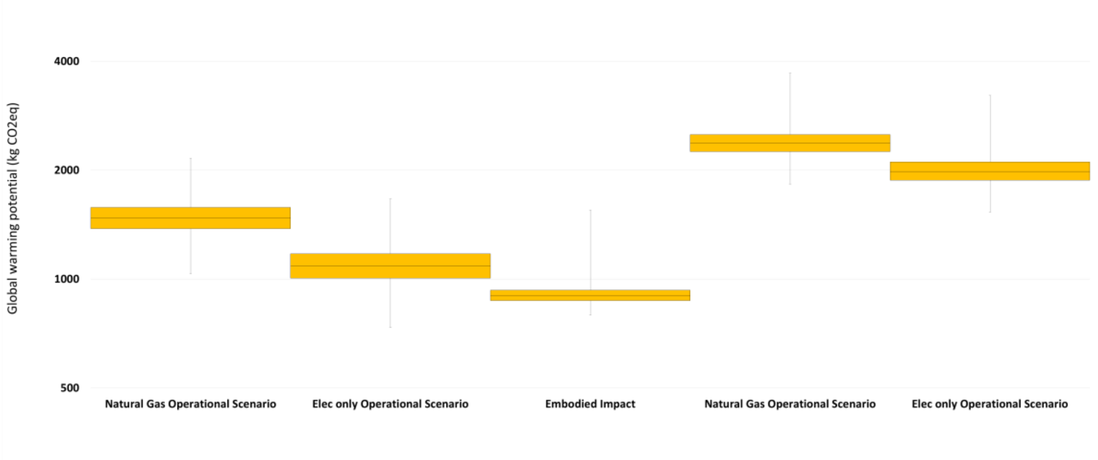

Fig.6. the total GWP results of the office building.

5 Conclusion, limitations and recommendations

The intent of this study was to provide a framework for design teams to generate more accurate and realistic environmental impact analysis in order to have a better idea about the building project while making important decisions at the conceptual stage. The novelty highlighted in this paper describes the model's different modules, which are integrated into each other based on an semi-/automated process by creating new BIM-LCA plug-in and improving the functionality of the existing tools so that users will be able to start the sustainable design of a proposed building project at the conceptual stage of its life cycle in a timely and cost-effective way. Using a BIM integrated platform moves the design decisions forward at the early stage especially when comparing different design alternatives, which is considered to be an attribute of this research.

There were several simplified assumptions in the proposed sample model which can be considered as important modelling limitations. In conducting the embodied impact analysis, there were several data gaps between the bills of materials with the available unit processes in the LCI database. The construction and maintenance activities were excluded from the embodied impacts assessment due to the lack of available data. The transportation distances to transport materials to site were assumed as a constant number (100km) during the building life cycle. The embodied impacts were assumed to be constant due to the lack of more detailed region-specific LCI data and whether these requirements should be changed through the life cycle of the project based on the climate change scenarios.

The creation of IDF files for energy analysis through Honeybee was done in a semi-automatic way since the identification of zones, spaces, construction, HVAC and schedules were required to be done by the user. To fully automate this process, this process could be integrated in the BIM-LCA interfaces. It is recommended that the proposed method is implemented in more case building from various types (i.e. low-rise, mid-rise and high-rise), various occupation types (i.e. residential, office, commercial) and various structural types (i.e. concrete, steel, wood) to be able to come up with more comparable and accurate analysis results in order to develop a climate change and grid mix decision support system at the early design stage.

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Perspective of Public-Private Partnership (PPP) in Various Economies

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Abstract
With the growth of economies and population worldwide, there is an increased demand for the development in various sectors and the country's sustainable development. For the modern economies, with the objective to minimize the overall costs and to increase efficiency, such huge investments cannot be funded by the government alone but with the involvement of private sector as well. There has been a significant popularity in the construction industry regarding the implementation of Public-Private Partnership (PPP) scheme as it is based on a long-term partnership concession on the basis of mutual appreciations of risks, costs and opportunities. The PPPs with innovative modern technology in different forms are being implemented for infrastructure development in both the developed and developing nations with diverse results. There is a larger and growing number of PPP practitioners within the government and private sector focusing on 'lessons learned' for PPP implementation. Although the PPP model is being implemented over the past three decades, various countries are still working on developing solid PPP policies and legal frameworks to govern such contracts. This paper aims to conduct a review on PPP literature, critiques on the history and modern trends in various economies, covering different regions in Europe, Asia and Middle East.

Keywords
Public-Private Partnership, PPP, History of PPP, Project Statistics, Challenges for PPP, Success failure criteria

1 Introduction

Provision of public infrastructure is the prime responsibility of the government, however, due to budgetary pressure different government tend to involve private sector for public services by implementing the tool - Public Private Partnership (PPP). Different countries practice PPP in various sectors. Due to various factors, most of the countries could not utilize the benefits of PPP effectively and face different challenges to implement PPP and to execute the PPP projects successfully. This paper presents an analysis on the various stages of PPP implementation in various economies covering different regions in Europe (United Kingdom, Germany), Asia (China, India) and Middle East (Saudi Arabia, Qatar and Sultanate of Oman). In this paper, the above mentioned economies are selected for the analysis , because PPP has been successfully adopted and actively considered for the economic growth of these countries. Brief history of PPP in the above countries, Statistics of project and most success/failure factors are discussed.

2 PPP in Various Economies

2.1 United Kingdom

2.1.1 Brief History

PPP was introduced first in the UK in 1992 (Rodney & Gallimore, 2002), in the form of the Private Finance Initiative (PFI) as a way of procuring public infrastructure by getting the private sector to build, finance and operate infrastructure under typical contracts of 25 to 30 years (Tieman, 2003). PFI accounted between 10 - 14 per cent of the Britain's entire yearly investment in public services.
As per (HM Treasury, May 2019), the private sector is not paid by the public sector entity for the asset during construction. A monthly fee referred to as a 'unitary charge' (UC) will be paid to the private sector provider upon operation and commencement of services by the asset, the public sector entity. The payment is mainly subjected to performance and ensures an incentive to meet the private sector provider performance obligations and reinforce the transfer of risk to the private sector.

2.1.2 PPP Project Statistics

As per the information (HM Treasury, May 2019) on average 55 contracts were signed a year between 1997 and 2010. 84 contracts have been signed at an average of 9 a year, since May 2010. As on 31st March 2018 (HM Treasury, May 2019), there were 704 current PFI and PF2 projects. The total capital value of the current portfolio was £57 billion (nominal), compared to £59.1 billion as at 31st March 2017.

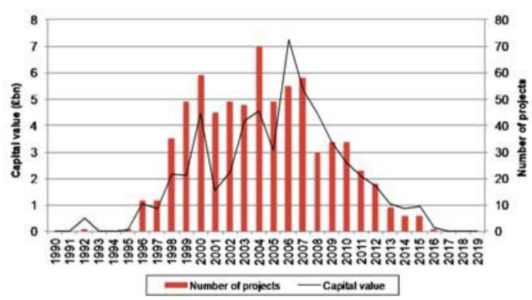

Figure 1 Portfolio of current PFI and PF2 projects - number and capital value by year of financial close (HM Treasury, May 2019)

Figure 1 shows the number of existing PFI and PF2 contracts that were signed (reached financial close) in each financial year and their capital values.

2.1.3 Challenges for PPP

A key criticism of the original PFI model was a lack of understanding and transparency of the financial returns earned by project company shareholders. To counter this, the government wanted the stakeholders under PF2 projects to provide their financial returns to HM Treasury. PFI projects involve long-term relationships, success can be achieved only if the public authority and the contractor approach the project in a spirit of partnership, with understanding of each other's business and a common vision of how best they can work together.

2.1.4 Success Failure Criteria

Governments believe that PPP/PFI procurement can provide a wide variety of net benefits for society, including: enhanced government capacity; innovation in delivering public services; reduction in the cost and time of project implementation; and transfer of major risk to the private sector, in order to secure value for money for taxpayers (Li, A, P. J., & C., 2015). Three Critical Success Factors (CSF)

– a strong private consortium, appropriate risk allocation and available financial market – emerge as being most important in the development of successful UK PPP/PFI projects (Li, A, P. J., & C., 2015).

2.2 China

2.2.1 Brief History

China has gone through three stages towards accepting the PPP model. The first stage was around the 1990s, which began with building power stations using the build-operate-transfer (BOT) model, and followed with investments in toll roads. The second stage began with the landmark issuance of an administrative rule in 2004 by the Ministry of Construction regarding the administration of concessions, as of which BOT, transfer-operate-transfer (TOT), build-own-operate (BOO) and other models became formally accepted. As the beginning of the third stage, the past several years witnessed a burst of growth of PPP in China. From 2013 onwards, the Chinese government started to promote PPP in more aspects of public product and public service fields.

The legislative framework of PPP mainly consists of relevant laws, regulations and regulatory documents. More than 90% of PPP projects were initiated by local governments in China (CPPPC, 2019) and these local Government and all the SOEs are liable to PPP policies.

2.2.2 PPP Project Statistics

A total of 4,815 projects have been managed, with an investment of ¥7.3 trillion by the end of 31 January 2019 (CPPPC, 2019). PPPs in China have grown at a drastic rate since 2014 under the promotion of the Ministry of Finance (Zhang, Ying Gao, Zhuo Feng, & Weizhuo Sun, 2015). Though before 2014, the number of PPPs in China was almost negligible, totalling 428 projects, the number almost got doubled every half year, reaching a total of 12,248 by the end of 2016. In 2017 when the central government issued several policies to control policy risk (see Figure 2) the sharp growth halted in mid-2017, After a six-month clampdown on illegal PPP operation, by early 2018, a total of 1,695 PPP projects, involving 1.8 trillion yuan (about US$284 billion) of project finance, had been terminated (Chen, 2018).

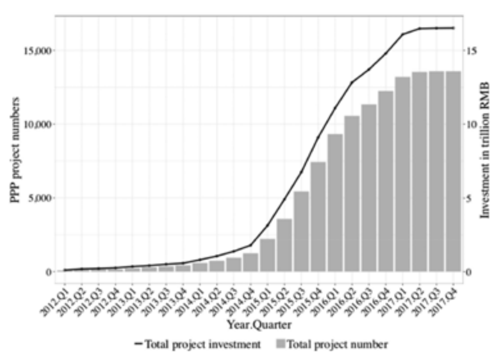

Figure 2 Accumulated PPP Projects, Number and Investment, 2012–17 [Data collected from the Ministry of Finance's PPP database on September 26, 2017.]

2.2.3 Challenges for PPP

For a long period, there was no laws in the area of PPPs in China. China's PPP plan was aggressive, but its implementation was poor (Petersen, 2010). Regulations, notices and orders played both positive and negative roles on the PPP market. Inadequate risk-sharing arrangements haunted the first generation of PPPs and resulted in large contract renegotiations. In 2002, the General Office of the State Council prohibited the practice of guaranteeing fixed returns for foreign companies at all levels of governments, forcing them to renegotiate many existing PPP contracts. As a consequence, the participation of foreign companies in PPPs in China gradually faded away (Wang, Yongjian, & Jing, 2012).

2.2.4 Success Failure Criteria

The top five important CSFs are ‘reasonable risk allocation’, ‘government support and guarantee’, ‘picking up the good project’, ‘a strong project consortium’ and ‘project technical feasibility’. It is also found from the data that factors such as ‘multi-benefit objectives’, ‘good governance’, ‘well-organised public agency’, ‘technology transfer’ and ‘social support’ are least important for assisting to achieve BOT projects’s success in China. However, some of the CSFs tend to be of different significance to the private sector compared to the public sector (Yang, M. Nisar, & Prakash Prabhakar, 2017).

2.3 Germany

2.3.1 Brief History

In Germany the first wave of PPP projects started shortly after the beginning of the new century. One of the first PPP projects was a tunnel called Warnowtunnel near the city of Rostock in the northern part of Germany. Under the PPP guidelines established, a value for money (VFM) test involved a PPP-Public Sector Comparator (PSC) comparison and is required to be applied in three steps during the course of the project development.

- Selecting the right project for PPP treatment
- Assess possible VFM gains prior to tender, when the PPP-PSC is calculated in a range to present different risk scenarios.
- PPP-PSC is calculated with data from negotiations with the preferred bidder.

2.3.2 PPP Project Statistics

Almost 200 projects with a total investment of €8.1 billion have been realised in building and road construction since 2003 which led to a savings of 13.7% (Offentlich-Private Partnerschaften in Deutschland, 2013). While construction projects are focusing on the areas of education, health and government, in the road sector the A-models, which is a six lane expansion of highway (between 2009-2015) are in high demand.

As shown in Figure 3, development of the German market for PPP was very weak in 2013. Only 12 PPP construction projects with an investment volume of approximately € 305 million and one municipal road project with a volume of approximately €10 million had been awarded.

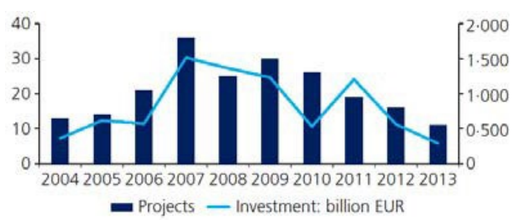

Figure 3 PPP in Germany until December 2013 (Jacob, 2014).

2.3.3 Challenges for PPP

Two critical challenges affecting the outcomes of the PPP are: (1) a participation deficit; and (2) a lack of integrity (Hüesker 2011; Moss and Hüesker 2010)

2.3.4 Success Failure Criteria

To create successful PPPs one has to reduce transaction costs and take into consideration the agency problem.The elucidations on transaction cost theory lead to the assumption that less specific PPP projects are "cheaper" with regard to transaction costs. Monitoring costs make up a considerable volume of overall transaction costs in PPP projects which can be reduced if the project partners cultivate a relationship based on open communication and trustworthiness.

As per the principal agent theory, PPPs can be turned to be successful when there is a general "fit" in the partnership. When the partnership lacks balance in expertise, this may lead to information asymmetries (Greer, Matthias Wismar, & Josep Figueras, 2016)

2.4 India

2.4.1 Brief History

During the First Five Year Plan (1951–1956), the government sought 'community support' for the construction of the irrigation canals. Thereafter in Seventh (1985–1990) and Ninth (1997–2002) Five Year Plans the government recognized the role of NGO's/Voluntary Organizations for social development. In early 1990s, a new model of public service delivery was established, where the role of public and private sectors were redefined.There has been a remarkable growth of PPP projects in India during last one and half decades.

2.4.2 PPP Project Statistics

During the period H1 2019, according to the PPI database of the World Bank, India has the second highest number of PPP projects. As on 06th December 2019, there are 1,824 infrastructure projects implemented by the Government on PPP basis which is in tune of INR 2,495,539.920 Crore (USD 340 billion)

2.4.3 Challenges for PPP

Since the whole concept of PPP is quite new in the country, there is no PPP regulation in India. The entire process of creating a PPP arrangement is very long and ridden with a lot of formalities. Many projects lack diligent studies and technical research. Project plans are of poor quality and lack attention to details. This creates problems related to scope changes and variations during project execution (Kutumbale & Dr. Vidya Telang, 2014).

2.4.4 Success Failure Criteria

As PPP sector is new in India and the parameters used in structuring of PPP cannot be the same every time, it is difficult to standardize a PPP format. The stake of the Central and State governments, responsibility and risk sharing in the project are circumstantial and are likely to vary from one contract to another. One of the most discussed problems related to PPPs is the lack of transparency and a strong legal framework (Kutumbale & Dr. Vidya Telang, 2014).

2.5 Saudi Arabia

2.5.1 Brief History

The idea of partnerships with the private sector appeared in Saudi government's official documents from the late 1970s. The Saudi Third Development Plan encouraged the establishment and operation of "joint venture partnership corporations" between state-owned enterprises in the petrochemical industries and private sector entities (Ministry of Economy and Planning [MEP], 1979, p. 224). The Fourth Development Plan did not limit these partnerships to a specific sector, but promoted "various new partnership arrangements between the public and private sectors relating especially to maintenance and operations projects" (MEP, 1984, p. 70). The Seventh Development Plan used privatization and partnerships interchangeably (MEP, 1999, p. 134).

2.5.2 PPP Project Statistics

The first project to mark the starting of PPPs in Saudi Arabia was the Shuaibah Independent Water and Power Plant (IWPP). The majority of Saudi Arabia's utility-related projects reached financial closure and was delivered on time. As there was lack of political resistance or restrictions on land allocations to the private sector, it has allowed significant involvement of the private sector in electricity and water generation.

The rising number of Muslim pilgrims arriving at the Hajj terminal at King Abdulaziz International Airport (KAIA) in Saudi Arabia, made PPPs for the delivery of airport infrastructure inevitable. Saudi Arabia's second airport, Prince Mohammad bin Abdulaziz International Airport, was fully expanded under a PPP agreement after touching its maximum capacity of 4 million passengers a year in 2009 (IFC, 2012). In the utilities sector, the independent power producers (IPP) project by SEC is with the state-owned Aramco for cogeneration of future electricity needs (MEED Projects, 2015).

2.5.3 Challenges for PPP

High-profile projects are running years behind the schedule, with cost over-runs worth billions of U.S. dollars ("Saudi Arabia's New Approach to Avoid Construction Overruns and Delays," 2015). There is no proper framework for large-scale PPP projects in the Kingdom. Saudi Arabia always followed traditional procurement for large infrastructure projects. Public sector control is expected to be a critical feature of the developing PPP model in the Kingdom. As expected, international sponsors experience frustration with inflexible specification requirements and stringent oversight of construction, operational and testing issues.

International sponsors find it difficult to follow Shari'ah-compliant PPP structures. In sectors like airports traditional 'procurement model is not appropriate instead innovative models will need to be developed and tested. All PPP projects in Saudi Arabia should be financed, constructed and operated pursuant to the principles of Saudi law which is difficult to follow for the sponsors, contractors and lenders who may not have prior experience with the Saudi judicial and legal framework (PPPs in SoudiArabia, 2016).

2.5.4 Success Failure Criteria

Lack of efficient risk management and mitigation mechanisms for projects has been considered as a critical failure factor by many researchers (Dubem I. Ikediashi, Stephen O, 2014). The following are the other most highly ranked factors identified for the causes of PPP project failures in Saudi Arabia, (1) Project management deficiencies, (2) Well defined legal framework, (3) Government interference, (4) Constraints imposed by stakeholders.

2.6 Qatar

2.6.1 Brief History

Qatar acknowledged the PPP phenomenon only recently. One of the long-term objectives of Qatar's National Vision 2030 is to encourage PPP (GSDP, 2008).

For involving the private sector in public sector projects within a solid framework that imparts development benefits to the State, including knowledge and skill transfer, a committee led by the Ministry of Economy and Trade was created to encourage PPP. Five PPP projects were implemented, including the launch of a land allocation project for the private sector to develop and operate schools, hospitals and tourist facilities. During the Qatar National Development Strategy (NDS-2 period (2018-2022)) a draft PPP law and strategy are expected to be issued.

2.6.2 PPP Project Statistics

PPP projects in Qatar had been exclusively focussed on IWPPs/IPPs. First IWPP project was the construction of the Al-Wusail IWPP. Ras Laffan was Qatar's first IWPP, followed by one IPP and another three IWPPs structured on 25-year BOOT contracts. A total of 6,500 MW of electricity, is generated in Qatar through PPP projects (Marakib, 2012). Kahrama engages in 25-year PWPAs with the IWPPs' project companies purchasing all of the generated water and electricity under the Qatar government's payment guarantee. No other PPP deals were signed until 2015.

2.6.3 Challenges for PPP

Qatar's Public Works Authority, Ashghal, is the key governmental entity in charge of infrastructure projects, which followed traditional EPC ("Public Works Authority," 2015). Unlike Kuwait and Saudi Arabia, where the private sector has financed and operated water treatment and sewage systems, Ashghal delivered these projects on an EPC basis due to the smaller size of Qatar, and abundance of financial support via state funding. Qatar did not make significant efforts to mobilize private finance for the infrastructure projects geared toward achieving Qatar's National Vision 2030, nor for projects needed for the 2022 FIFA World Cup as NDS-2011 promised.

Qatar did not consider PPP approach for mega infrastructure projects for a number of reasons. First, there was pressure on the government to deliver on-time infrastructure for the 2022 FIFA World Cup, and this did not go with the complexities and lengthy procedures normally needed for PPP contracts. Second, both the hesitance of international private sector companies to assume the projects' risks and the availability of sufficient funds during a period of peak prices for gas and oil prices meant that the government of Qatar was not ready to use PPPs to finance the works (Foreman, 2012).

2.6.4 Success Failure Criteria

In the NDS-2, the reference to maximising the PPP participation were emphasized to be one among the success factors.

2.7 Sultanate of Oman

2.7.1 Brief History

During the 1990s, the authorities in the region were looking for private sector to get involved and provide power at competitive rates. Five IPPs were launched in 2000 in Oman. With the low oil prices and extremely tight budgets, the Government of Oman was looking upon the PPP as a way to boost economic growth by implementing investment and diversification agenda for the country's ninth five-year plan for the period 2016-20, and its Vision 2040. In December 2015, the taskforce hired a consortium of consultants to advise on creating the PPP legal framework and expansion of PPP procurement.

In July 2019, Oman released the long-awaited Public Private Partnerships (PPP) Law (Decree No. 52/2019). which empowered the newly created Public Authority for Privatisation and Partnership (PAPP) to oversee PPP projects in Oman. However, a Royal Decree No. 110/2020 was issued on 18th August 2020 regarding the cancellation of the Public Authority for Privatization and Partnership and that it would now be part of the Ministry of Finance (ONA, 2020).

2.7.2 PPP Project Statistics

In Oman, the PAPP were examining as many as 38 projects for implementation via the PPP in various sectors (Prabhu, Oman weighs 38 projects for PPP based implementation, 2019). The government aimed to deliver priority public projects valued at around RO 2.5 billion through PPP and also played a key role in driving forward the PPP initiative. Other large PPP projects include Port Sultan Qaboos Waterfront, a $1.3bn mixed-use development and Sultan Qaboos Medical City, a $780m hospital complex. With a vision to build a world-class logistics city, Khazaen Economic City, the master developer of the largest public-private partnership (PPP) in Oman, had awarded the first construction package in tune of RO 9.2m.
In November 2019, the Asyad Group - which is an integrated transport and logistics flagship of the Omani government had invited private developers to invest and develop new complexes of its wholly-owned subsidiary.The Oman's sewage treatment agency under the flagship of Haya Water, were preparing to launch their first Public Private Partnership (PPP) project in 2020's.

2.7.3 Challenges for PPP

An extensive programme of training to ensure that Ministries who are not used to dealing with the private sector can properly manage these contracts as the PPP requires a different approach and cannot be taken in similar perspective to that of an Employer – Contractor relationship.

2.7.4 Success Failure Criteria

PPPs can offer a proper alternative to traditional procurement methods; but, a number of conditions must be met to create a successful PPP. These include environmental and project-related critical success factors such as availability and effectiveness of proper and regulatory framework for PPP; availability of financial market (local and international); political support and stability; proper risk allocation and sharing among the project stakeholders; and finally, clear project brief and client outcomes.

3 Conclusion

The paper analysed the implementation of PPP in countries like United Kingdom, Germany, China, India, Saudi Arabia, Qatar and Sultanate of Oman where PPP is considered as a major alternative for the economic development. The development stages of PPP have been studied and detailed statistics, challenges and Success failure Criteria of PPP Projects in all the above countries have been documented and Tabulated as shown in Table 1. Project case studies from the above countries reveals that despite of the significant potential of PPP, initial expectations on the size and pace of project development have not been met in many cases.

All the countries face certain challenges for the successful completion of the PPP projects. Though there exist different laws and authorities to ensure the smooth functioning of PPP, these authorities are in turn controlled and managed by the existing government bodies, which makes different stages of the PPP projects tedious. The sharing of the underlying risk of the projects are not properly defined, analysed and shared between the participating public and private parties. All PPP projects should undergo diligent studies and thorough technical research before implementation.To conclude, every country should have a separate body which can control the PPP projects independently and the whole process, concept to realization, should be simple and transparent. Latest technologies and innovative systems in construction management should be adopted in all stages of PPP implementation. Moreover, an independent project management consultancy should be appointed to ensure the smooth functioning and successful completion of the PPP projects.

Table 1. Challenges and SFC of PPP in Various Ecnomies

Countries	Challenges	Success failure Criteria
United Kingdom	Lack of understanding and transparency of the financial returns earned by project shareholders. Long term partnership between the stakeholders.	A strong private consortium, Appropriate risk allocation and available financial market
China	No laws in the area of PPP, Inadequate risk-sharing arrangements	Reasonable risk allocation, government support and guarantee, picking up the good project, a strong project consortium and project technical feasibility.
Germany	Participation deficit, Lack of integrity	Reduction in transaction Cost, Lacks balance in expertise in partnership
India	External Factors, No proper Legal and Regulatory framework, Financial Issues, Contractual Frameworks	PPP regulation, Lack of transparency, Control of scope changes and variation.
Saudi Arabia	No proper framework, inflexible specification requirements, Shari'ah-compliant PPP system, judicial and legal framework	Project management deficiencies,Well defined legal framework, Government interference, Constraints imposed by stakeholders, Risk Allocation and Management
Qatar	Complex and lengthy procedures, Increased risks and the unavailability of sufficient funds	The reference in NDS-2, to maximising the PPP participation
Sultanate of Oman	Difficulty in undersating of PPP, Legal Framework, In different Approach from different ministies	Proper regulatory framework, Availability of financial market, Political support and stability, Proper risk allocation and clear project brief.

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Using Artificial Intelligence to Automate the Quantity Takeoff Process

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Abstract
Quantity takeoff is the process of obtaining quantity measurements from construction plans and providing a list of materials needed to complete a project. Despite the recent and wide use of BIM tools, most construction plans and documents are still 2D drawings on electronic files or sheets of paper. Consequently, estimators and contractors need to measure items and then perform calculations from 2D drawings. This is why the quantity takeoff is the most time-consuming activity in creating the cost estimate and prone to error (like many other manual activities). It is fair to say that almost all new construction drawings are available (or created) as digital files and PDF is the most common file format for sharing the project plans and documents. A review of commercially available takeoff software for construction reveals that we are now able to accurately measure the quantities from digital files and even send them to spreadsheet programs, such as Microsoft Excel. These new software tools can greatly speed up the takeoff process and increase efficiencies. But they still need someone with a thorough understanding of architectural and construction terminologies and symbols to assign the measured quantities to the right cost items. Intelligent document processing is the next generation of automation and measuring quantities from a variety of PDF documents. In this study, we use Artificial Intelligence technologies such as natural language processing (NLP) and machine learning (ML) to identify and extract relevant quantities from a set of 2D construction drawings.

Keywords
Quantity Take-off, Cost Estimate, Artificial Intelligence

1 Introduction

The aim of cost estimating is to forecast, approximate, assess or calculate the probable cost of a project computed based on available information (Juszczyk 2017). Indeed, the cost estimating process has largely been a matter of importance to the success and failures of a construction project. The cost of a construction project needs to be estimated within a specified accuracy range, but the largest obstacles standing in front of a cost estimate, particularly in the early stage, are lack of preliminary information and larger uncertainties as a result of engineering solutions (Elmousalami 2020). Consequently, the critical process of cost estimation has become a major challenge for cost estimators. As such, to overcome this lack of detailed information, cost estimation techniques are used to approximate the cost within an acceptable accuracy range (Waty *et al.* 2018). Construction takeoff, as an essential aspect of the cost estimation process, undergoes many changes during the building process. In general, different phases of construction takeoff are highly dependent on the knowledge and experience of estimators and the use of historical company records that compiled cost information from previous completed projects (Famiyeh *et al.* 2017). Furthermore, all cost estimation software requires the use of associated and/or additional databases that contain the unit costs and other industry data needed to prepare an estimate (Lee *et al.* 2014). To determine the cost of each material item, the estimators may use their database of a third-party database (such as RSMeans in the US) or may seek a bid from a material supplier (Pratt 2018). Indeed, take-offs created via the use of computer tools still require human operators and interpreters no differently than take-offs produced manually. These computer tools can reduce the risk of miscalculation and save time and money, however, they do not eliminate the estimating skills and knowledge.

It is fair to say that almost all new construction drawings are available as digital files, and PDF is the most common file format for sharing the project plans and documents. In short, an estimator uses construction drawings as inputs and extracts material quantities. It is expected to have a list of all of the materials necessary to complete a project by taking off the quantities. Unit count, linear length, surface area, volume, and physical weights are the common units of measurement. Items such as doors, windows, or lights are listed by unit count. Linear length is used for materials such as lumber, pipe, and standard shape structural members. The surface area is used for surface and covering materials such as roof and wall finishing. Concrete as well as lumber (e.g. board feet) should be listed by their volume quantities, and the cost of steel and earthwork can also be estimated by weight. These quantities will be linked to cost values and combined with overhead, labour, subcontractor, and equipment costs to provide a final detailed estimate (Schaufelberger and Holm 2017).

Computers have become an inevitable part of cost estimating. Even in a manual quantity takeoff, cost estimators often utilize an excel spreadsheet, word processor, or other computer tools during the process. In contrast to a manual quantity takeoff, digital quantity take-offs are completed with the assistance of digital takeoff software. Taking off quantities has been facilitated by recent advances in computer-aided design (CAD) and building information modelling (BIM) programs (Abanda *et al.* 2017). A gap exists between the use of existing methods and the availability of an automated that measures quantities from a variety of 2D construction drawings. Research in artificial intelligence (AI) areas indicated that the recently developed machine learning and AI algorithms had potential application in developing a quantity takeoff and enhancing cost estimating services (Tijanić *et al.* 2019). The primary objective of this paper is to propose AI techniques for automation and measuring quantities from a variety of 2D construction documents. The ultimate goal is to accurately count and measure takeoff items for estimators lacking decades of field experience in the construction sector. To achieve this goal, this study explains the use of AI technologies such as natural language processing (NLP) and machine learning (ML) to identify and extract relevant quantities from a set of 2D construction drawings.

2 Review of Construction Takeoff Software

Quantity takeoff is a time-consuming, error-prone, repetitive, and sometimes tedious process if conducted manually. AI-powered algorithms have helped key players to tackle some of the challenges including cost and schedule (Mohammadpour *et al.* 2019). To overcome such difficulties, various software tools have been developed in recent years to automate the quantity takeoff to some degree. These tools feature some capabilities that help estimators to take off their desired quantities with further ease and higher accuracy. Takeoff software tools have consistently improved over time and now they offer a variety of cutting-edge features that can significantly raise the accuracy and speed of the quantity takeoff process. This section briefly introduces some of the most common and practical features of takeoff software tools, then compares nine of the most robust and well-known tools, and finally reveals some of the major gaps of the existing tools in achieving full automation. Some of the key features of the most common takeoff software tools are illustrated in Table 1.

Table 1. Key Features of Commercially Available Takeoff Software Tools

Feature	Brief Explanation
Object detection and count	Automatically detect a specific object on drawings and count the number of its appearances
1-D, 2-D, and 3-D measurement	Automatically measure the length, area, or volume of a line, 2-D, or 3-D shape specified by the user
Embedded items count	Automatically count the number of items that are inside or assembled to a predefined main item
Predefined configuration addition	Allow users to add and store items with customized configuration, embedded items, and assemblies
Collaborative environment	Allow various users to work on the same project through a cloud-based environment
Multi-layer plans	Allow users to define multiple layers and separately takeoff quantities on each layer
Multi-format import	Allow import of plans and drawings with different format types
Excel-compatible export	Automatically prepare Excel-exportable quantity takeoff reports

Although most of the developed takeoff software tools share the aforementioned features, there are some differences between them in terms of the convenience of the user interface, the level of allowable customization, the span of applicability, the compatibility with different platforms, etc. A comparison between nine of the most well-known takeoff software tools is provided in Table 2. Once a construction drawing is added to these tools, a list of all measurements and dimensions is generated and the estimator can apply prices to each item or object. Although digital quantity take-offs tools are the quickest method available in the market, the method is still time-consuming and relies heavily on the estimator's experience.

Table 2. Comparison of Common Takeoff Software Tools

Program Name	Platform	User Interface	Applicability	Striking Features
STACK	Online on any device	Powerful and modern	General contractors, concrete contractors, home builders, interior finishers, landscape specialists, masons, roofers, and others	Highly collaborative environment, compatibility with other software tools
PlanSwift	Windows operating system	Convenient	General contractors, concrete, drywall, electrical, flooring, framing, decking contractors,	Compatible data import, easy customization

			HVAC, insulation, landscape, masonry, painting, and plumbing	
Bluebeam Revu	On-device installation with real-time collaboration capabilities	Intermediate-level	Almost any specialty from design to bidding	Powerful managerial features
Countfire	Online on any device	Modern and intuitive	electrical contractors and estimators	Robust counting feature, powerful customer service
On Center	Windows and cloud-based versions	Clean and easy to follow	Almost any specialty from biding to building	Highly collaborative environment, powerful customization
PrebuiltML	Windows operating system	Acceptable	concrete, roofing, siding, flooring, masonry, and paint contractors, as well as commercial dealers, framers, and builders	Access to various materials database and cost information
Square	Online on any device	Modern and intuitive	General contractors, plumbers, roofers, and many other specialists	Easy customization
eTakeoff Dimension	Windows operating system	Weak and dated	Almost any specialty and general contractor	Easy customization
Buildee	Online on any device	Modern, simple, and intuitive	Almost any specialty	Fast and direct data import
STACK	Online on any device	Powerful and modern	General contractors, concrete contractors, home builders, interior finishers, landscape specialists, masons, roofers, and others	Highly collaborative environment, compatibility with other software tools
PlanSwift	Windows operating system	Convenient	General contractors, concrete, drywall, electrical, flooring, framing, decking contractors, HVAC, insulation, landscape, masonry, painting, and plumbing	Compatible data import, easy customization
Bluebeam Revu	On-device installation with real-time collaboration capabilities	Intermediate-level	Almost any specialty from design to bidding	Powerful managerial features
Countfire	Online on any device	Modern and intuitive	electrical contractors and estimators	Robust counting feature, powerful customer service
On Center	Windows and cloud-based versions	Clean and easy to follow	Almost any specialty from biding to building	Highly collaborative environment, powerful customization
PrebuiltML	Only on Windows operating system	Acceptable	concrete, roofing, siding, flooring, masonry, and paint contractors, as well as commercial dealers, framers, and builders	Access to various materials database and cost information
Square	Online on any device	Modern and intuitive	General contractors, plumbers, roofers, and many other specialists	Easy customization
eTakeoff Dimension	Windows operating system	Weak and dated	Almost any specialty and general contractor	Easy customization
Buildee	Online on any device	Modern, simple, and intuitive	Almost any specialty	Fast and direct data import

These software tools can greatly speed up the takeoff process and increase efficiencies. Despite the considerable recent improvements in takeoff software tools and their eye-catching capabilities, there is still a long way towards full automation of the quantity takeoff process. The rest of this paper is centred around the use of AI to further raise the automation of the takeoff process.

3 Research Method –AI Techniques for Estimating Costs

Developing an intelligent agent requires capturing the knowledge of experts and professionals in their areas of expertise. This knowledge can be stored in the form of programmable algorithms and rules; such as IF-THEN constructs. In the present study, we model or represent the knowledge of skilled estimators in a way that an AI system can process. As shown in Figure 1, the AI techniques vary greatly as to their purposes and the information about a facility's construction requirements and associated activities. We consider 12 distinct groups of construction projects to find the common ground between AI techniques used in the quantity takeoff and cost estimating process. When an estimator is given a set of construction drawings, the estimator determines what quantities (or items/services) should be considered. Such items and services are commonly listed in the project solicitation. Also, standards like MasterFormat assists cost estimators in organizing information and searching for specific information in consistent locations. The first step for developing an intelligent cost estimator agent is to generate a structured representation of the task domains. The most recent edition of MasterFormat including 35 divisions is used in the study to list and organize the items and services.

Each division can be further divided into some sections. For example, erosion control is a section in the earthwork division. The estimator goes through each section and finds the drawing that contains the relevant information. NLP is an AI technology that helps machines read construction drawings and find drawings that may contain the relevant information for the takeoff process. We use the RSMeans estimating database to list the keywords associated with each section and division. For example, "silt fence" or "erosion control mat" can be listed for estimating the cost of the erosion control section. The artificial agent can also learn from experience without explicit adding of the keywords. In this case, a combination of NLP and machine learning is used to add new keywords to the knowledge database. If an estimator sees a concrete washout area in the erosion and sedimentation control plan, the estimator includes the cost of this washout area in the erosion control section. Similarly, the artificial agent uses NLP to understand the legend in a drawing and uses machine learning to include that in the list of items or services for a given section (if there is a cost item in the database). Otherwise, the intelligent agent learns to ignore the item (e.g. boundary line or limits of construction).

The next step is the quantity takeoff. There are a variety of commercially available software tools suitable for taking off quantities and measuring areas and lengths. The estimator utilizes these tools or CAD programs to extract the size of the concrete slab, number of windows, or length of silt fence shown in the erosion control plan. Image processing is a technology to generate information (e.g. quantities) out of an image (or a digital construction drawing). Image processing that uses machine learning enables us to measure objects in the drawing and automate the PDF analysis process. Machine learning plays a major role here because the artificial agent should learn the style and shape of objects in the legend and then measure the size (or quantity) of objects with a similar style or shape in the drawing. In addition, the scale of the drawing should be used to convert the measurement to correct dimensions. Image processing is used for linear scales (also called graphical scales) and NLP is used for verbal scales or representative fraction scales.

Converting quantities into construction cost estimates requires considerable experience and knowledge of available resources, existing construction methods, and market conditions. In some cases, the method of construction is stated in the project specification (e.g. method of concrete delivery or placement). Even in those cases, the estimator has options to choose for performing the task. For example, an exterior painting specification may state a three-coat system for a job but the estimator can choose between spray painting and brushwork. In such cases, the available resources or the lowest price determine the unit price and/or assemblies. This situation applies to many labour-intensive jobs too, where available skilled workers result in a different unit price. Our analysis of the distinct groups of construction shows that there are a finite number of scenarios that an estimator has the options to choose for the method of construction.

Therefore, it is possible to write a specific set of IF-THEN rules to choose the unit price and/or assemblies. These deterministic expert systems have proven themselves in estimating and bidding for construction projects (Smith 2017). As shown in Figure 1, estimators tend to choose the most likely unit price when provided with some options. The project specifications and availability of resources limit those options. The most likely unit price is not necessarily the median value, but instead, market conditions will dictate where unit prices lie (e.g. lower price in an elastic market).

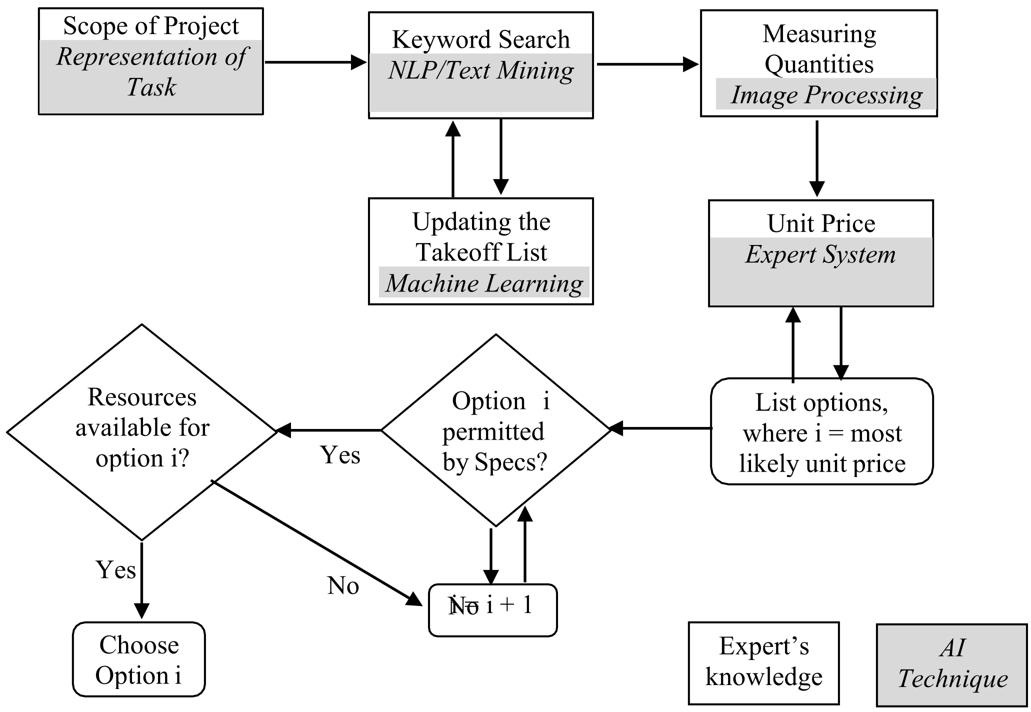

Figure 1. AI techniques used in the takeoff process

The quantity takeoff process enables us to calculate the cost of materials, labours, and equipment and as a result, provide the foundation for calculating the indirect costs. The project cost is calculated by adding project overheads, mark-up cost or profit, contingency, and allowance for construction risks. The AI techniques used in the takeoff process are described in the following subsections using simple examples. Table 3 lists the potential applications of AI techniques in the quantity takeoff and cost estimating process of 12 distinct groups of construction projects.

Table 3. Role of AI Techniques in Automating Construction Cost Estimation

Groups of Construction	NLP/Text Mining	Machine Learning	Image Processing	Expert System
Demolish	High	Moderate	Moderate	Moderate
Concrete	High	High	High	Low
Masonry	High	High	High	High
Metals	High	Moderate	High	Low
Wood	Moderate	High	High	Low
Thermal and Moisture Protection	High	Moderate	High	Low
Openings	High	Moderate	Moderate	Moderate
Finishes	High	High	High	High
Earthwork	High	High	High	High
Plumbing	Moderate	High	High	High
Electrical	Moderate	High	Moderate	High
Mechanical (HVAC)	High	High	Moderate	High

3.1 NLP/Text Mining

Text Mining (TM), also referred to as text data mining is the process of deriving high-quality information from textual data. TM involves automatically extracting information from different written resources to discover new, previously unknown information (Williams and Gong 2014). TM uses a variety of algorithms and methodologies including NLP for structuring and processing the input text. NLP is mainly concerned with how computers can be used to understand, process, and analyse natural language text or speech. Because NLP aims for human-like performance, it is considered an AI discipline (Al Qady et al. 2010). The application of NLP technology has significantly increased in healthcare, risk management, insurance, customer service, and advertising over the past decade.

A 3,000 square foot (around 280 m^2) residential building in Texas is used as the basis for our case study. The construction plan set contains 30 pages of drawings and specifications. To estimate the cost of walls, we train the agent to index the keyword “wall” and generate a tag cloud to find the most frequently used words in the drawings. We extracted more than 156 “wall” keywords in the project drawings were extracted and listed the drawings with at least ten results in Table 4 (e.g. site plan with two results or window and door schedule with two results are not listed). With the aid of a concordance tool, we could identify the preceding and following contexts in the concordance of the keyword “wall”. NLP also is used to clean regular expressions and filter out most of the unwanted texts. Note that only the preceding and following words with high frequency are listed in Table 4.

Table 4. Result of the text analysis for the keyword wall (a case study)

Drawing	Count	Frequent Context
Material & Room Finish Schedule	9	Blocking Wall (2)/ Adjacent Wall (3)
Entry Level Plan	23	Exterior Wall (4)/ Interior Wall (3)/ Wall (6)
Lower Level Plan	22	Exterior Wall (5)/ Interior Wall (4)/ Retaining Wall (2)
Wall Sections	9	Siding Wall (5)/ Retaining Wall (2)
Interior Elevations	9	WD Wall (2)/Wall Sconce (2)/ Wall Paper (4)
Interior Details	11	Wall Framing (2)/ Finish Wall (2)/ Wall Partition (2)

3.2 Image Processing

Digital image processing (DIP), a subfield of digital signal processing, is the application of a computer to process and manipulate digital images using efficient algorithms (Gonzalez and Woods 2018). The NLP technology leads the intelligent agent to focus on the drawing with the most frequent cases (e.g. lower level plan for "wall" in the case study). The most common measurements made by an image processing system are the number of similar objects (count), perimeter (length), and area. Continuing with the wall example, 32 items are obtained from the Lower Level Plan with the pixel as the basic unit. The processed plan (or image) is calibrated to establish the relationship between each pixel and the size of the real object. The digital image is resized using the drawing scale of 1/4" = 1'-0" in this example. The result of the image processing is shown in Table 5 for the Lower Level Plan. The wall items are specified by the NLP/Text Mining. We can train the agent with machine learning techniques to ignore the Count and Area measurements.

Table 5. Result of the image processing for wall measurement (a case study)

Wall Type	Count	Length (m)	Area (m^2)
Exterior 2x6 Wall with Brick	0	0	0
Exterior 2x6 Wall with Hardie Siding	4	51	18.1
Interior 2x4 Wall	14	46	15.3
Interior 2x6 Wall	1	6	0.8
2x4 Partial Height Wall	13	43	13.2
2x4 Wall Below	0	0	0

3.3 Machine Learning

ML is a branch of artificial intelligence, the study of computer programs that automatically learn from experience and improve their performance for some tasks (Rafiei and Adeli 2018). In the wall example, a machine learning technique called dimensionality reduction is used to remove the count and area quantities from a data set. In general, it is not possible to directly measure the quantity of vertical objects such as walls from 2D top views such as floor plans. Another machine learning method called artificial neural network is used to convert the extracted measurements to desired quantities. In the wall example, a hidden layer for the height of the walls is added to calculate the surface area.

3.4 Expert System

An expert system (ES) is a computer program that is designed to imitate the decision-making ability of human experts by reasoning through a knowledge base, represented mainly as if-then rules rather than through conventional procedural code, using an inference engine (Kulkarni *et al.* 2017). In the wall example, the framing of the wall is specified and the artificial agent needs to process the framing in board footage. This can be learned by the list of materials defined for the wall framing.

4 Findings and Conclusions

Estimators regularly spend many hours working on quantity takeoff to estimate the cost of the projects. This study focused on the use of AI technologies such as NLP, ML, and ES to identify and extract quantities from a set of 2D construction drawings. AI techniques vary depends on their applications and purposes for a project's requirements and associated activities. We consider 12 distinct groups of construction projects to find the common ground between AI techniques used in the quantity takeoff and cost estimating process. An AI-based system, with access to drawings of the buildings, can develop quantity takeoff based on the knowledge it gains from the drawings and data in the database. To address that, we modeled the knowledge of skilled estimators in a way that an AI system can process. To ensure the cost estimating process fits the AI strategy, the common takeoff software tools were reviewed and the role of AI techniques in automating construction and cost estimation was studied. The construction drawings of a residential building were selected as a case study to implement AI techniques including NLP to extract the number of walls in the drawings for quantity takeoff and DIP and ML to estimate the wall areas as well as the number of walls (vertical objects) from floor plans (2D top view). This knowledge was stored in the form of programmable algorithms and rules; such as IF-THEN constructs.

It is important to note that AI is based on past decisions, activities, or performances and needs to train data. Data acquisition and storage is one of the main challenges related to AI combined with restrictions on data sharing and data ownership that can cause legal challenges for the company. As a result, the larger construction companies have more resources and data to benefit more from AI applications. Researchers respond to this challenge by developing ML and NLP datasets that represent or include construction drawings. Meanwhile, AI applications in cost estimating can create positive momentum and it makes sense to start with small use cases and built upon them for more extensive use of AI for quantity takeoff and cost estimation in construction projects. The study proposed AI techniques appropriate for taking off quantities in a 2D construction drawing and explained their role in the takeoff process.

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Paradigm shift of Claims Management to Digital Space

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Abstract
Claims in the construction industry are considered unavoidable and can have severe consequences if not managed properly. Claims management has taken prominence in recent years due to the large number of disputes occurring. Inefficiency and lack of competency of both the process and personnel make claims management a cumbersome affair to both the claimants and respondents. This paper aims to review the transformation of the claims management process from being a manual process to a semi-automated one, and how the advanced information and communication technology (ICT) available can be leveraged to further enhance the management of claims, as well as to address the aforementioned issues. The paper begins by discussing the claims management process in brief and illustrates the need to have a system aided by ICT for reducing manual effort and thereby improving the efficiency and the accuracy of the processes involved. The paper then reviews the existing claims management systems available, the impact of IR4.0 and emerging technologies on claims management practice, before discussing the need for a fully integrated cloud-based claims management system capable of bringing about the aforementioned needs and desired benefits.

Key words
BIM, Claims Management Systems, Cloud computing in construction, Construction claims.

1 Introduction

The construction industry is the largest in the world in terms of volume and resources (Becerik 2004). Governments look to the construction industry to boost their economy by investing in infrastructure projects (Narayan and Tan 2019). However, the industry is fragmented, unorganised and labour-intensive which makes the task of managing and completing a project complex and tedious. The size of projects and related complex processes generate considerable risks and uncertainties. These uncertainties eventually give rise to claims which have a considerable impact on the financial balance of the project (Stojadinović 2018). Furthermore, studies have also shown that a considerable number of claims have been settled only by litigation, which is both costly and time-consuming (Bakhary et al. 2015).

It is a fact that claims management is a tedious process involving a considerable amount of documentation and synthesising a large volume of information (Shahhosseini and Hajarolasvadi 2021). The key element in claims management is the presentation of information for verification and the realisation of claims. This involves extensive documentation and processing it manually involves a sizable volume of resources, which eventually also increases the overall cost of the project

(Shahhosseini and Hajarolasvadi 2021). The increase in cost has a considerable impact on the profit margins (Hadi 2018). Also, the manual processing of claims management poses serious challenges not only to the claimants but the defendants as well, especially if the opposing party is well-prepared aided by ICT-based systems. (Tan and Anumba 2010).

The current trend of moving to the digital space presents an opportunity to have systems that make the processes easy, efficient and expeditious. Furthermore, the digital space has provided an opportunity to integrate the fragmented construction industry by providing boundaryless and compatible working platforms. This paper reviews the journey of the claims management process through the years and the transformation of the process to the digital space. This study aims to review the attempts to transform the claims management process through automation in the last 30 years. This study reviews the claims management process and the challenges encountered thereof. Further, it not only reviews the development of information systems for managing claims but also the individual processes like document management, dispute resolution etc. which form a part of the claims management. Finally, it presents a case for adopting cloud computing technology in managing claims.

2 Claims management – an inevitable process

Claims management is a widely studied domain in the construction industry. Being an integral part of contract administration, the concept of claims gains prominence due to its financial implications, both for the project and the organisation. Most researchers seem to agree that claims are inevitable within a project. Efficient handling of claims management paves the way for the successful closure of a project (Shen et al. 2017). The process of claims management starting from identification to negotiation for closure, if not followed diligently raises the possibility of escalating to a dispute and subsequently a bitter ending (Bakhary et al. 2015).

Claims in the construction industry is an extensively researched area (El-Ghrory et al. 2019). Considerable research has been undertaken to identify the types and causes of claims under various conditions and types of projects. The source of claims can be attributed to any stakeholder and can arise at any phase of the project. All forms of contract have clauses imbibed in them which stipulate processes for dealing with claims. However, the ambiguity in contract clauses and their subsequent interpretation by various parties may give rise to conflict. Thus, the management of claims becomes an essential part of the project management process (Project Management Institute 2016).

The lack of resources in terms of knowledge, technical know-how and lack of competency of staff make the claims management process challenging and problematic for both the claimants and respondents (Tan et al. 2018). Studies have shown that lack of awareness has resulted in claims being overlooked which have eventually cost the parties concerned dearly (Tan et al. 2018). The lack of contract knowledge and awareness among staff is a major problem in the identification of any claim (Bakhary et al. 2015). Timely notification of claims, a basic step in claims management, has also been a perennial problem faced by most contractors (Hayati et al. 2019; Bakhary et al. 2015; Chovichien and Tochaiwat 2004). Coupled with the poor knowledge of staff and poor documentation processes adopted, especially onsite, further jeopardizes the successful completion of the claims management process (Bakhary et al. 2015). Improper, inefficient and incorrect storage of information and records are a stumbling block in the preparation of proper documentation for claims examination and presentation (Hayati et al. 2019). Poor negotiation skills and inadequate documentation put the claimants on a backfoot and can eventually end up manifesting a loss for the claimants (Hayati et al. 2019).

Studies have suggested that claims management should be treated with the utmost importance for successful project closure. This effort should ensure that the process does not escalate into litigation (Bakhary et al. 2015). Project Management Book of Knowledge (PMBOK) construction extension (2016) presents an elaborate process to manage construction claims (Project Management Institute 2016). It suggests adopting the claims management process from the beginning of the project (Project Management Institute 2016). The importance of documentation and timely administration of a contract for claims has been stressed time and again by various researchers. Minimising the manual process ensures that the process of claims management is carried out accurately and with alacrity (Hayati et al. 2019; Tan and Anumba 2011).

3 The shift to digital space

The financial constraints coupled with the increasing age of our workforce globally is forcing a shift towards automation in all industries including construction (Woodhead et al. 2018). The rapid development of IT in recent years has enabled the processes to be digitised with considerable success and at a cheaper cost. The call for the adoption of IT across the construction industry is not new. The adoption of IT to support claims management was suggested in the late 1980's to early 1990's by various researchers. AbouRizk and Dozzi (1993) illustrated how a simulated model of actual scenario could help resolve construction dispute thus providing a strong basis for adopting IT in construction.

3.1 Claims Management System – Need

Time is a critical element in the process of claims management. All the forms of contract stipulate a time limit for the claims management process. Studies have shown that much of the time is spent on locating the documents and history for claims preparation (El-Ghrory et al. 2019). This leaves insufficient time for the preparation of the documents, and it results in a poor presentation for claims. Carrying out the processes manually not only consumes resources, but also tends give leeway for errors such as overlooking records or missing of documents. Automation of processes like storing and retrieving of documents reduce the time taken for these processes (Vidogah and Ndekugri 1998). Studies have suggested that adoption of information technology have aided in the improvement of project management processes (Ren et al. 2001). A well-designed decision support system can improve the efficiency and accuracy of decisions.

3.2 Claims Management System – Requirements

A claims management system (CMS) should have several features which make the system potent and user friendly. A good CMS should have a centralised database, provide contractual support, facilitate online claims transmittal, categorise claim types, track claims status, raise reminders and alerts, be user friendly and facilitate customisation (EL-Ghrory et al. 2019; Tan et al. 2011). Further, the system should cater to all major forms of contract and be commercially viable (Tan et al. 2011). Finally, a good CMS should minimise the manual processes by automating as many of these processes as possible.

3.3 Claims Management System – Early developments and Support

The earliest systems developed for managing claims and disputes were primarily rule-based expert systems (Alkass et al. 1995; Diekmann and Kim 1992; Arditi and Patel 1989; Kim and Adams 1989). The drawback of these systems was the handling of grey areas in contract administration (Bubbers and Christian 1992). Further, the lack of sufficient data proved to be a handicap in generating rules for all possible situations (Bubbers and Christian 1992). The low capability of computer hardware restricted the volume and types of data processing (Alkass et al. 1995). The limited infrastructure facilities and lack of integration meant that the whole process was still predominantly manual and provided modest benefits (Alkass et al. 1995). Despite the concept of the expert system being considered in its twilight stage, the development of newer technologies has kept research in this area alive till recently. For instance, Elziny et al. (2016) developed an expert system (DRExM) utilising Visual Basic, MS Access and Visual Rule Studio, to manage dispute resolution in Egyptian construction projects.

One of the key elements to ensure the successful administration of claims is the documentation supporting claims and management of information. The early stages looked at digitising the process of administering and storage of documentation (Bjork 2001). Bjork (2001) also suggested the use of the internet for document management. It was purported that the digitisation of document management would yield a saving of 5 – 10% of the project cost (Bjork 2001). Database Management systems like MS Access, SQL server etc. provided a viable database management system which could be adopted for efficient documentation and further support the claims management process (Al-Sabah et al. 2003).

3.4 Claims Management System – Advancement and Maturity

The next stage of advancement came with the improved technologies such as Artificial Neural Networks (ANN) (Palaneeswaran et al. 2006), Fuzzy logic (Cheung et al. 2001), Data mining Techniques (Al Khaldi et al. 2019) etc. ANN, a step above the prior expert system, provided a platform for synthesising more complex processes with multi-variant functions. It was considered a ‘thinking system’ and had the potential to evaluate all possible outcomes. One drawback of ANN was the overfitting of data which make the results unreliable (Palaneeswaran et al. 2006). Palaneeswaran et al. (2006) suggested the adoption of ANN for predicting cost overrun and contractual claims. Chapalkar et al. (2015) presented a model for predicting the outcome of construction claim disputes using ANN. The model showed an accuracy of over 75% when the prototype was tested on existing cases (Chapalkar et al. 2015).

Cheung et al. (2001) adopted fuzzy logic to propose a construction dispute evaluation model for predicting disputes due to claims. Nasirzadeh et al. (2019) proposed a system using a hybrid-fuzzy-SD method to assess the financial consequences of claims. Al Khaldi et al. (2019) adopted data mining techniques to identify the main causes of construction claims in Egypt. With CMS attainting maturity, project management systems were designed to support claims management. Abdel-Khalek et al. (2019) proposed a method to prepare and analyse claims using Primavera Contract Management (PCM) program and Primavera P6. However, despite their maturity, all these systems were stand-alone, and a considerable number of processes were still manual and decentralised. With decision making become more centralised, a common platform for the process became the need of the hour.

3.5 Web based Claims Management Systems

A lack of adequate communication, knowledge transfer and integration etc. presented a strong case to move towards web-enabled systems (Alshawi and Ingirige 2003). The period of 2000 – 2010 saw an increased interest in the research of the application of web-based systems in the construction industry. These applications ranged from systems for managing information and knowledge (Ozorhon et al. 2014; Chassiakos and Sakellaropoulos 2008, Ahuja et al. 2006, Scott et al. 2003), document management systems (Forcada et al. 2007), contract management (Kwok et al. 2007), predicting construction claims (Chau 2007), project monitoring (Palaneeswaran and Kumaraswamy 2008) to complete project management (Nitithamyong and Skibniewski 2004; Chan and Leung 2004).

The web-based claims management system proposed by Tan and Anumba (2010) consists of a transaction system to manage the workflow and documentation and also allows capture of the knowledge from each process (Tan and Anumba 2010). The system also has the potential of integration with BIM which can enhance the effectiveness of claims management process. Even though this system has been developed based on the PAM contract as used in Malaysia, the concept can be applied to other forms of contract as well. Hayati et al. (2018) developed a prototype claims management system to minimise disputes in Design and Build infrastructure projects. This system provides for risk identification and prevention, contract management, claims administration and documentation and dispute resolution (Hayati et al. 2018). Though, developed for a Design and Build form of contract only, the authors opine that the system can be adapted for other forms of contract with further research and development (Hayati et al. 2018).

Though Web-based systems present many advantages, especially real-time knowledge transfer, they are not without drawbacks. Internet access, stability and bandwidth is a major problem in the implementation of web-based applications (Nitithamyong and Skibniewski 2004). Further challenges to the adoption of web-based systems in practice include system reliability, password barriers, software interoperability and collaborative maturity (Nitithamyong and Skibniewski 2004).

3.6 BIM and Claims Management – A comprehensive solution?

The advent of BIM over recent years has propagated a new paradigm in the field of project management in the construction industry (Wong et al. 2014). Originally, the use of BIM was predominantly for design, however, further developments in recent years have added additional dimensions which envisage the project in its entirety starting from concept through to facilities management (Shahhosseini and Hajarolasvadi 2021). The 3D element of BIM can assist contractors to monitor the project virtually and improve the process of site management (Gardezi et al. 2013). The fourth (4D) and fifth (5D) dimensions offer assistance towards monitoring of projects in terms of time and cost respectively (Gibbs et al. 2013, Gardezi et al. 2013). BIM also provides an additional tool in the process of retrieving information, which is a key element in claims management.

Marzouk et al. (2018) illustrated the need to adopt BIM in claims management with a case study. Their aim is to facilitate forecasting of the possibilities of claim events through visualisation (Marzouk et al. 2018). Gardezi et.al. (2013) proposed the adoption of BIM as a conflict resolution tool for the Malaysian construction industry. Their framework proposed BIM as an integrated project delivery tool that can efficiently manage and evaluate the onsite construction process and minimise the causes of disputes due to claims (Gardezi et al. 2013). Ali et al. (2020) developed a BIM-based CMS for managing Extension of Time (EOT) claims. Autodesk Revit was used as the BIM platform with the BIMCMS as a plugin (Ali et al. 2020). However, the system still had some manual features which limited its full potential (Ali et al. 2020).

The advantages presented by BIM, especially concerning information stored, make it a potent tool in managing projects more efficiently (Shahhosseini and Hajarolasvadi 2021; Gibbs et al. 2013). Studies have shown that BIM enhances the overall performance of the project in terms of design, onsite coordination, quality control and compliance, delays and budgets and safety (Eadie et al. 2013). Improved performances in the project, directly and indirectly, co-relate to reduced claims. The added advantage BIM presents is the virtual visualisation which gives the decision-makers a feel of reality. The need for trained personnel, high capital investment, legal issues and cultural reluctance are some of the issues which make wide implementation of BIM a challenging affair (Eadie et al. 2013). Further, like other systems, lack of immediate benefit can prevent the stakeholders from investing in BIM.

4 Industrial revolution 4.0 – the future

The current age is often referred to as the Industrial Revolution 4.0 (IR4.0), the first three being mechanisation, electrification, and mass production and finally electronics and digitalisation (Alaloul et al. 2020; Woodhead et al. 2018; Oesterreich and Teuteberg 2016). The essence of IR4.0 is the move towards the digital space with the help of the latest technologies. IR4.0 presents tremendous opportunities for the construction industry across seven factors namely political, economic, social, technological, environmental, legal and security (Alaloul et al. 2020). Concepts and technologies like IOT (Woodhead et al. 2018), Big Data (Narayan and Tan 2019), Blockchain (Belle 2017) and Smart technologies (Maskuriy et al. 2019) are gaining visibility in the construction industry. Studies have shown that technologies like BIM, cloud computing, mobile computing, modularisation are in vogue and being commercialised (Oesterreich and Teuteberg 2016). Considering the fragmented nature of the construction industry with multiple stakeholders and multiple layers of decision-making levels, the implementation of IR4.0 processes does present a viable solution for convergence.

4.1 Cloud computing in project management – opportunities and challenges

Cloud computing, one of the key technologies within the IR4.0 scenario, presents a multitude of advantages for the construction industry. The primary opportunity cloud computing presents is that it promotes sustainable construction by going paperless (Rawai et al. 2013). Cloud platforms provide an opportunity to manage remotely; a facility that becomes very useful for organisations involved in running projects which are geographically diverse (Garyaev and Rybakova 2018). Cloud space also enables an efficient, economic way of managing resources as it facilitates the sharing of digital spaces (Rawai et al. 2013). Cloud-based BIM technology enables an advanced level of project management with better collaboration, communication, and visualisation (Wong et al. 2014). Access to the internet, stable connectivity, data security, financial viability and problems encountered by third-party service providers are some of the challenges in cloud computing (Narayan and Tan 2019). The handling of a cloud, both hardware and software, platform by a third party does raise scepticism among end-users in terms of security (Narayan and Tan 2019). The lack of clarity on the ownership, responsibility and liability of cloud-based BIM models does present some legal challenges (Wong et al. 2014).

4.2 Cloud based systems for claims management – the emerging paradigm

In the last 25 years, considerable efforts have been made to facilitate the automation of claims management process or part thereof. Every stage of development endeavoured to bridge the gaps and further improve on the previous stage. Expert Systems attempted to replicate human expert knowledge. Artificial Neural Networks attempted to improve upon Expert Systems to make systems look more human. Web-based systems looked at improving the efficiency in communication, access, and knowledge transfer. BIM further improved the claims management process through visualisation. Furthermore, newer technologies are being adopted to develop systems to improve upon the existing concepts like more advanced Expert System shells.

Most of the systems developed so far focus on only one or a few areas of claims management. An integrated system which encompasses the complete solution of knowledge storage and transfer, CMS and BIM for visualisation can provide wide-reaching benefits for effective claims management. However, adoption of such a system, despite the underlying benefits, would be a challenge due to the high initial investment on the system. Though, studies have focused on improving the process using ICT, the rate of return of investment is still not clearly illustrated, thus deterring the stakeholders from adopting ICT systems. Cloud-based systems present a possible solution with ready to use systems and could attract a greater number of users towards adopting ICT. The user would pay only for the service which would be far less compared to investing in the entire system and eliminate the problems related to ICT, especially for small and medium enterprises (Jardim-Goncalves and Grilo 2010).

The implementation of a cloud-based framework within the construction industry commenced after 2010 (Kumar et al. 2010). Cloud computing, though a relatively new concept in IT, is now rapidly evolving (Garyaev and Rybakova 2018). Current studies are focussing on implementation of cloud-based systems in various aspects of construction industry including claims management. The conceptual model for a cloud-based knowledge brokering platform for managing construction claims proposed by Tan and Anumba (2018) provides the much-needed thrust to the process of claims as it combines both the knowledge transfer system and the CMS. Chen et al. (2019) have proposed a contract management system based on a cloud Enterprise Resource Planning (ERP) system and developed for small and medium-sized enterprises in China. Li et al. (2020) have proposed a cloud-based conceptual model for managing the higher dimension knowledge in BIM.

5 Conclusion

It has been widely acknowledged that the digital space is the future of the world, and the current pandemic has given a glimpse of things to come. The adoption and implementation of IR4.0 is being extensively explored across both geographies and industries. In the past construction industry has been slow to adopt newer technologies, however, the current scenario presents an opportunity to change this perception. Studies have identified claims to be one of the most disruptive processes in construction industry and carrying out the processes manually creates further challenges. Considerable losses are incurred due to poor management of the claims process by both the claimant and the defendants. The competitive nature of the industry illustrates the need for automation of the claims management process and increased use of ICT. The review of literature of current systems suggests that significant effort has been made in the research of automating the claims management processes or part thereof with moderate success. The processes in construction industry are still predominantly manual with organisations still reluctant to adopt ICT for various reasons. There is another school of thought which opines that all process cannot be automated especially in areas of claims management like negotiation and dispute resolution (El-Ghrory et al. 2019). ICT systems will not be able to replicate human decision-making processes which in a way contradicts the IR4.0 paradigm and smart construction which attempt to minimise human intervention. Studies have suggested that adoption of ICT for communication, storage, document management can help save resources in terms of time, space, and cost. Though, in the process of decision making, having systems to replicate human thinking is still a challenge, adoption of ICT does help in analytics. Thus, this calls for a balanced approach in the adoption of ICT systems to achieve optimal result. Cloud computing has the potential to facilitate a wider adoption of ICT in construction. Cloud computing, which provides software, platform and infrastructure as service, can alleviate common problems of ICT faced like heavy investment and interoperability and thus provide a wider reach of use of ICT (Jardim-Goncalves and Grilo 2010). Cloud computing being the future, a system based on cloud computing would assist in further improving the claims management process.

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Track 8

Agile and Lean Thinking

Development of Integrated Framework Based on Agile Principles and BIM Functionalities

An Exploration of the Potential for Using Modular Housing Solutions to Address the UK's Housing Shortage

Resilience Engineering

Efficient Utilization of Public-Private Partnerships (PPPs) to Develop Resilient And Sustainable Public Infrastructure

Strategies of Urban Resilience Related to the Built Environment: An Overview of the Literature

Policies and Regulations

Challenges to the Adoption of Strategies and Regulations for Energy Efficiency Initiatives in the Retrofitting of Retail Centers

Development of Integrated Framework Based on Agile Principles And BIM Functionalities

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ABSTRACT

Building information modelling implementation in construction industry requires changing the process and proper management approach to deliver successful projects in terms of design, construction, operation and manufacturing. This paper discusses alternative management approach to support BIM application in construction projects. Agile project management integrates with BIM in order to develop new two-dimensional framework to lead construction project teams into effective implementation of BIM functionalities and agile principles. The endeavour of integrating BIM and Agile is to deliver value in terms of minimizing wastes and rework, motivating individuals, early project delivery, better communication and collaboration, satisfying customer and effective adaptation of changes. This paper evaluates the associations between 12 agile principles and 13 BIM functionalities; and assesses how agile principles facilitate the implementation of BIM. This paper utilizes questionnaire survey to collect data from professionals in construction and software industries to verify the two-dimensional integrated framework. The main finding of the study include: (a) 75% of respondents agreed that BIM functionality of reusing of data model supports agile principle of customer satisfaction ; (b) 78% of respondents agreed that BIM functionality of construction simulation supports agile principle of welcoming changes; (c) 72% of respondents agreed that BIM functionality of visualization supports agile principle of priority of working product; and (d) 81% of respondents agreed that BIM functionality of automated cost estimation supports agile principle of simplicity.

Keywords: Agile Project Management, Agility Principles, Building Information Modelling

1. INTRODUCTION

Construction industry management approach is facing problems during project lifecycle. Researchers over the time developed an alternative management system to start overcoming these challenges. Meanwhile, agile project management left a positive and effective print in software and manufacturing industries. Therefore, Agile will be considered as the management method to be applied in construction industry. Moreover, the technology revolution in construction industry started to apply and develop better method of 3D and 4D modelling called BIM "Building Information Modelling". This paper will integrate agile project management principles with Building Information Modelling functionalities to develop an alternative management approach for construction industry. This paper will focus on "Enhancing agile application in construction projects using building information modelling". This paper will discuss Agile BIM framework development as well. BIM is considered not only as software but also a method that supports team members and provides a faster result to the management and construction team during project lifecycle.

2. AGILE BIM FRAMEWORK

Agile BIM framework identified in this paper is to show how to link between agile principles and BIM functionalities. This framework links between management, design, construction and procurement phases. Agile BIM approach is not only about following the framework but it is also about how the teams behave within the framework. Uikey and Suman (2012) described project manager behaviour within agile approach as "In traditional project management, the role of the project manager is more of a command and control type, where the project manager is the commander and team members are the followers. Any type of change in the software development environment is managed by the project manager and necessary actions are directed to the team. But in today's modern project management approach, like agile, the role of the project manager is redefined as a guide and mentor, working together with the team. The teams in agile methodologies are self-organized and motivated, the role of the project manager is to support and help the team to accomplish the task" (Uikey and Suman, 2012). This study develops and verifies a conceptual integrated framework which maps the relationships between agile principles and BIM functionalities.

- First dimension is based on agile project management with 12 principles.
- Second dimension represent Building information modelling with 13 functionalities.

Building Information Modelling needs proper management system to ensure delivery of the project and collaboration between team stakeholders. Agile project management is proved as a successful management method for the past years in manufacturing and software industries. BIM functionalities and agile principles are studied and analysed with 32 interactions (Sacks et al., 2010). Managers, developers, construction executives, designers and management teams working in construction industry will be affected by the benefits of Agile BIM development strategy adaptation. A framework will be developed to ensure BIM and Agile fits and interact together (Sacks et al., 2010). Table 1 shows an integrated matrix between 12 agile principles and 13 BIM functions. Agile principles are motivating individual to support BIM functionalities and adding value to the management process. Table 2 presents a sample of 10 of these integrations between agile and BIM. Omar and Elhag (2019) studied agile principles and BIM functionalities. That research evaluated 32 relationships to develop 2D integrated framework in order to enhance application of Agile in construction projects using BIM (Omar and Elhag, 2019).

3. RESEARCH METHODOLOGY

This paper considered two research methodologies to obtain professionals experience and opinion in order to validate integration between agile principles and BIM functionalities.

3.1 Questionnaire Survey

Questionnaire survey is mostly used for collecting of information throughout a survey. The structure of the survey is designed through sequence of questions such as scaling data, rating questions, multiple choices and type of questions. The survey can be distributed into individuals in person or online (Cohen et al., 2013).

3.2 Framework

Framework is a study to serve and to build a proper understanding of a research. This paper covers a framework by listing 12 agile principles and 13 BIM functionalities. Agile BIM framework shows integrations between agile principles and BIM functionalities by numbering process to be discussed in Table 2. Framework is an understanding of a problem to be presented and specified in theoretical way to support the research. It also helps to analysis the research data and to choose research design (Grant and Osanloo, 2014).

Table 1 Agile BIM Integrated Framework

Agile Principles/BIM Functionalities	Visualiza tion	Rapid Generation of Multiple design alternatives	Reuse of model data for predictive analysis	Automated cost estimation	Maintain of information and design model integrity	Automated generation of drawings and documents	Collaboration in design and construction	Rapid generation of construction plan	Construction process simulation	4D visualization of construction schedule	Online communication of product process	Computer controlled fabrication	Integration with project partners
Satisfy customer			24						12	15			
Welcome changes						14	8	10	13	16		22	29
Frequent Deliverables		3										23	
Working together							9				19		30
Motivate Individuals													
Face to Face Conversation											20		31
Priority for working product	1							11					
Sustainable Development					6		17					25	
Technical Excellence			4			7						26	
Simplicity				5						18		27	
Self-Organizing Teams											21		32
More effective Iterations		2										28	

Table 2 Agile BIM Framework Integration 10 to 19

10	Changes affect project plan. BIM rapid generation of construction plan allows agile project management to adopt changes and satisfy customer. BIM and Agile integration helps to generate plan and analysis effect on project duration.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
11	BIM ability to generate continues plans will allow agile project management to support and provide customer with correct duration and completion date of the project. This integration will increase customer trust and satisfaction. Agile is enhanced by BIM functionality to adjust priorities of activities in order to deliver iterations as per work conditions.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
12	BIM ability to simulate the project model during design and construction process by using 3D modelling of project structure supports agile management team to coordinate and collect more details about customer needs and requirements. This integration will increase customer collaborating and satisfaction.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
13	BIM ability to simulate project design and construction process is supporting agile project management approach to implement changes required during project life cycle. Simulation functionality allows customer and Agile team to understand the effect of these changes on project process, cost and duration.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
14	BIM automated generation of documents and drawings allows agile to implement changes. Agile team will be able to provide construction team with necessary drawings and documents affected by changes in short period of time. This integration provides accurate results and save time and effort.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
15	BIM 4D visualization of construction process and scheduling is supporting agile team to provide customer proper understanding of cost, time and work process of the project.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
16	BIM 4D visualization is supporting agile to implement changes and increase ability to evaluate effects of these changes. 4D visualization is supporting lean principles to eliminate wastes and non-adding value activities.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
17	BIM functionality of collaboration between design and construction supports agile principle to involve stakeholders during design process to implement sustainable material, reduce wastes and to study project consumption of energy.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
18	4D visualization of construction schedule is supporting agile principle of simplicity by providing less documentation and reports. BIM digital data obtained from model is used once needed by any parties involved in the project. This use of technology will save time and effort during project lifecycle.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)
19	BIM technology is providing online communication of product process that supporting agile project management to involve all stakeholders of the project. Communication between owner, designers, execution team, suppliers and manufacturer is required during design and construction process to ensure best quality and value to the project.	(Sacks et al., 2010) - (Nir, 2014) - (Opelt et al., 2013) - (Eastman et al., 2011) - (Hardin, 2009)

4. PROFESSIONALS RATINGS TO AGILE BIM INTEGRATIONS

This section discusses the integrated Agile BIM conceptual framework. The questionnaire survey targeted construction professionals representing clients, contractors and consulting organisations. The survey received 70 responses out of 120, with response rate of 58%. The following questions are discussed in depth according to the experiences and opinions of the respondents on the relationships between BIM functionalities and Agile Principles. The following questions only covers part of the survey conducted to verify and confirm all 32 integration.

4.1 BIM functionality of reusing of model data for predictive analysis will support agile principles of customer satisfaction and technical excellence.

This question targeted professionals in construction industry to evaluate their rating toward Agile BIM integration between BIM functionality of reusing of data supporting agile principles of customer satisfaction and technical excellence. Figure 4.1 shows that 75% of respondents rated the integration between reusing of data model and customer satisfaction as agree and strongly agree. Also, 86% of respondents rated integration between reusing of model data and technical excellence as agree and strongly agree. Facility management after project completion are using BIM model in the operation system and to generate accurate As-Built drawings (Eastman et al., 2011). This integration is supporting the customer during operation stage of the project and provides more satisfaction. Also, BIM is meeting owner needs and requirements in term of quality by providing a model that is comply with contract specifications (Liu et al., 2016). This model will be reused during project lifecycle by different stakeholders who will allow controlling project quality. Agile project management team will be enhanced by this functionality of reusing the model data by different stakeholders in the project and provides more satisfaction, good design and technical excellence to the customer and the project.

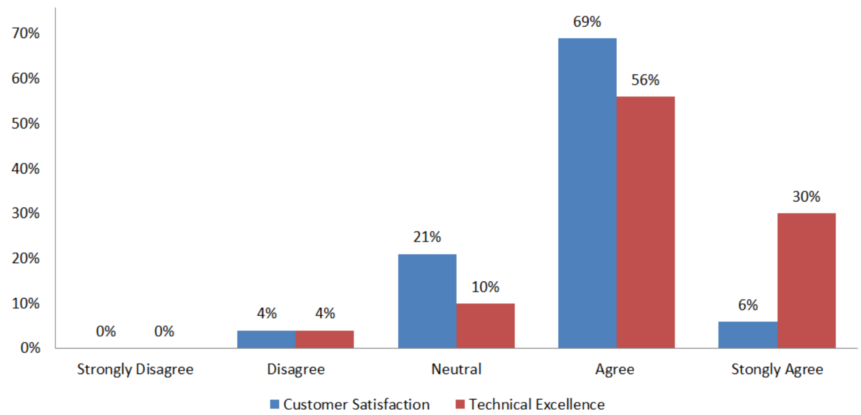

Figure 4.1 BIM functionality of reusing of model data for predictive analysis will support agile principles of customer satisfaction and technical excellence

4.2 BIM functionality of construction process simulation will support agile principles of customer satisfaction and welcome changes

This question targeted professionals in construction industry to evaluate the support of BIM functionality of construction process simulation toward agile principles of customer satisfaction and welcome changes. Figure 4.2 shows that 76% of respondents rated customer satisfaction supported by construction simulation between agree and strongly agree. Meanwhile, 78% of respondents are rated welcome changes supported by construction simulation between agree and strongly agree. This paper discussed BIM efficiency in adopting changes and providing visualization throughout process of simulation to the customer and stakeholders in order to provide better understanding and information sharing (Eastman et al., 2011). Agile defined as "Accept changes in requirements even late in development. Agile processes use changes to the competitive advantage of customers" (Opelt et al., 2013). Moreover, Agility allows agile team to manage customer needs and requirements in order to satisfy end user needs (Goodpasture, 2010). On the other hand, BIM enables engineers to simulate the work by more than one discipline (Arayici et al., 2012). BIM technology is providing virtual simulation for project operation system and helps stakeholders to understand owner needs and changes (Eastman et al., 2011).

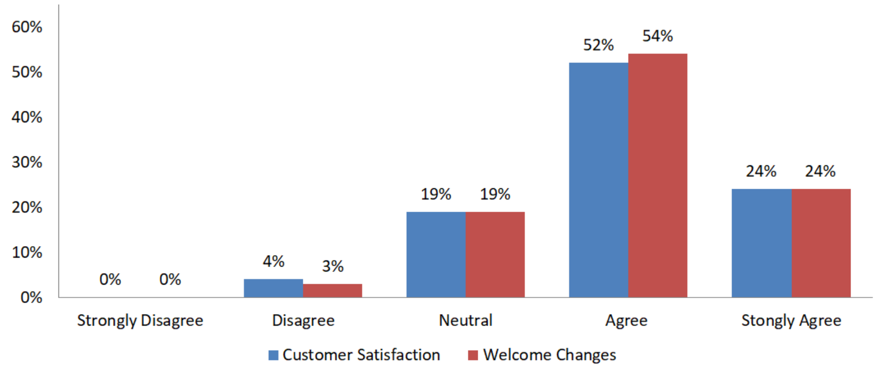

Figure 4.2 BIM functionality of construction process simulation will support agile principles of customer satisfaction and welcome changes

4.3 BIM functionality of visualization will support agile principle of priority of working product

This question targeted respondents in construction industry to evaluate their opinions regarding the integration between BIM functionality of visualization and agile principle of priority of working product. Figure 4.3 shows that 72% of respondents agreed and strongly agreed with BIM visualization functionality supporting priority of working product.

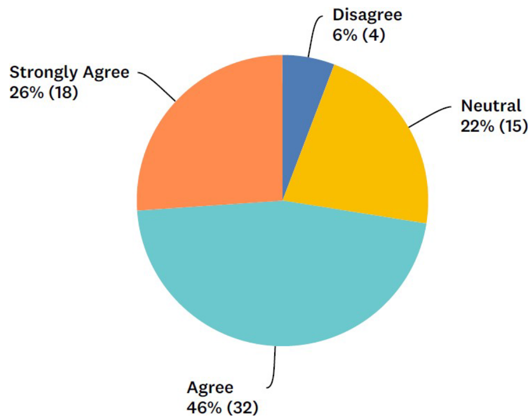

Figure 4.3 BIM functionality of visualization will support agile principle of priority of working product

BIM technology of modelling and visualization is bringing the project to life by providing enough results to the investor, designers and agile management team to have better visualization and understanding of the project functionalities and construction process data

(Tomek and Kalinichuk, 2015).Moreover, visualization helps design and management teams to understand customer requirements by simulating the project model and applying changes required (Bloomberg, 2013). BIM defined as "BIM was most frequent perceived of as a toll for visualizing and coordinating AEC work and avoiding errors and omissions" (Barlish and Sullivan, 2012). Agile principle of delivering early product is a priority to the agile team in order to satisfy the customer and making success (Opelt et al., 2013). BIM functionality allows agile team to visualize construction process and adopt changes required by customer in order to finalize iteration to be delivered to the customer.

4.4 BIM functionality of automated cost estimation will support agile principle of simplicity

This survey targeted professionals in construction industry to evaluate the support of BIM functionality of automated cost estimation supporting agile principle of simplicity. Figure 4.4 shows that 81% of respondents agreed and strongly agreed with BIM cost estimation supporting agile simplicity. BIM technology provides cash flow for better understanding of cost estimation during project lifecycle (Eastman et al., 2011). Moreover, BIM is providing advantages to construction projects such as project cost estimation, proper analysis and cost reduction, supporting reduction in insurance claims (Hardin, 2009). Although, BIM is capable to provide better financial control and cost minimizing during construction project (Arayici et al., 2012). On the other hand, agile methodology of project management had a principle of simplicity which is defined as "Simplicity. The art of maximizing the amount of work not done is essential" (Opelt et al., 2013). Agile principle of simplicity is to add value to the project by reducing the cost (Highsmith, 2010).

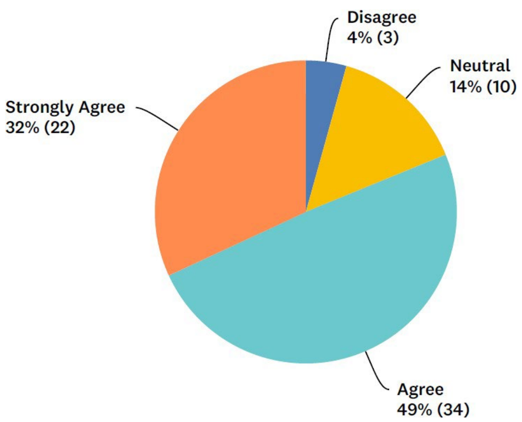

Figure 4.4 BIM functionality of automated cost estimation will support agile principle of simplicity

4.5 BIM functionality of rapid generation of construction plan will support agile principles of welcome changes and priority for working product

This question targeted opinions of professionals in construction industry to evaluate the support of BIM rapid generation of construction plan toward agile principles of welcoming changes and priority of working product. Figure 4.5 shows that 74% of respondents agreed and strongly agreed with BIM functionality to support agile principle of welcoming changes. Meanwhile, 78% of respondents' agreed and strongly agreed with rapid generation of construction plans to support priority of working product. BIM responding to the market changes by providing continuous plans as per changes occur during project lifecycle (Eastman et al., 2011). BIM technology can adjust construction process by providing planning and controlling over industry development implementation within construction project (Nowotarski and Pasławski, 2016). Agile aims are to keep priority to deliver progress during construction projects. Agility defined delivery of working product as "Our top priority is to satisfy customer though early and continuous delivery" (Opelt et al., 2013). All these studies conclude that BIM provides support to project management teams to develop updated plans during adoption of changes.

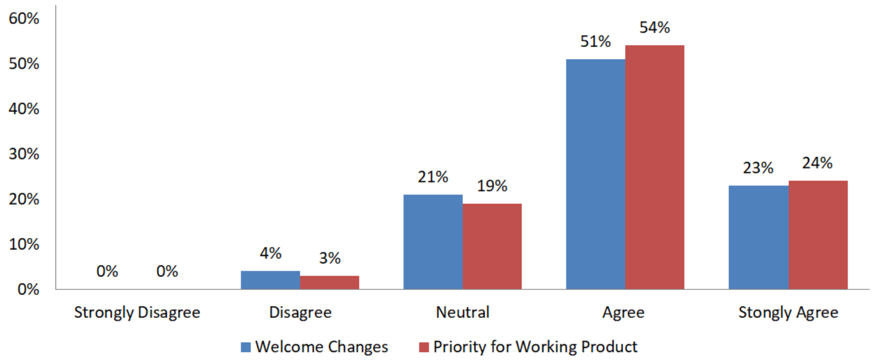

Figure 4.5 BIM functionality of rapid generation of construction plan will support agile principles of welcome changes and priority for working product

4.6 BIM functionality of 4D visualization of construction schedule will support agile principles of customer satisfaction, welcome changes and simplicity

This survey targeted respondents of professionals in construction industry to rate BIM functionality of 4D visualization supporting agile principles based on their experience in the industry. Figure 4.6 shows that 81% of respondents agreed and strongly agreed that 4D visualization will support agile principle of customer satisfaction. Although, 90% of respondents agreed and strongly agreed that 4D visualization will support agile principle of welcome changes. Also, 82% of professionals agreed and strongly agreed that 4D visualization will support agile principle of simplicity.

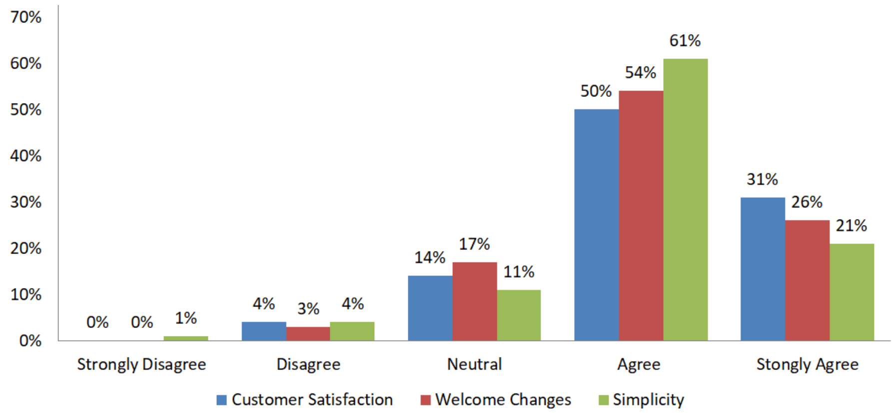

Figure 4.6 BIM functionality of 4D visualization of construction schedule will support agile principle of customer satisfaction, welcome changes and simplicity

Agile project management team are supporting designer by providing more flexibility and simplicity to receive changes (Bloomberg, 2013). BIM 4D visualization is supporting agile team by its technology and data analysis. During project construction, the hardest thing to do is to make changes. But BIM 4D visualization is solving this issue for customer and stakeholders (Bloomberg, 2013). Moreover, BIM technology is providing 4D modelling that helps in planning system in construction industry. Also, it provides simulation of building construction that enables stakeholders to know the activities day by day (Eastman et al., 2011). Agile principles are welcoming changes at any time by applying simplicity during accepting and removing of non-necessary activities (Nir, 2014). BIM functionality of 4D visualization is supporting and providing a tool to the designer and management team to satisfy customer needs and requirements.

4.7 BIM functionality of automated generation of drawing and documents will support agile principles of welcome changes and technical excellence

This survey includes a question of Agile BIM integration to be rated in order to validate the 2D framework developed in this research. Figure 4.7 shows the results of respondents' answers regarding BIM functionality of automated generation of drawings and documents supporting agile principles of welcoming changes and technical excellence. 75% of professionals agreed and strongly agreed toward BIM functionality supporting agile principle of welcoming changes. Meanwhile 70% of respondents agreed and strongly agreed on the support of BIM functionality toward agile principle of technical excellence. BIM helps to provide 2D drawings for all plans and elevation at any time or stage during project lifecycle (Eastman et al., 2011). Also, BIM is providing accurate 2D drawings (Arayici et al., 2012). BIM allows stakeholders to share the digital model data in order to generate 2D drawings, fabrication of material and sharing accurate information (Ghaffarianhoseini et al., 2017). Moreover, agile project management methods of handling construction projects are by accepting changes at any time and maintaining good design and technical excellence (Nir, 2014). BIM is supporting agile during construction stage by providing flexibility once changes applied to generate accurate drawings. Although, BIM functionality of automated drawings at any time or stage supports quality of drawings and data shared between stakeholders. This is leading into technical excellence during construction stages.

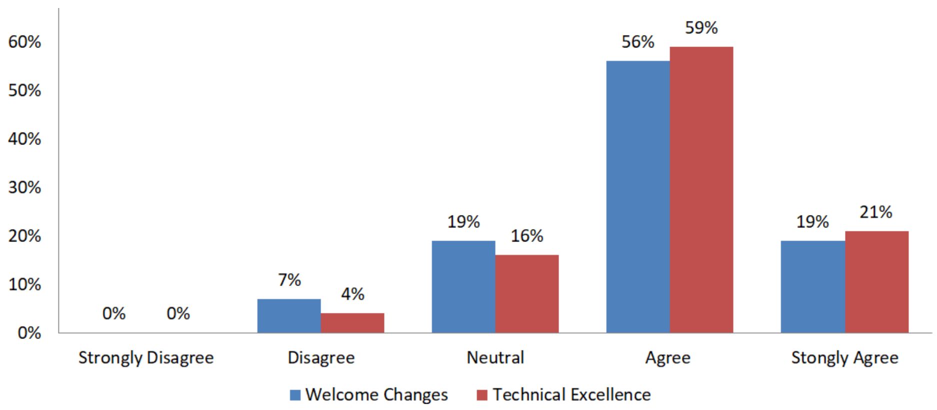

Figure 4.7 BIM functionality of automated generation of drawing and documents will support agile principle of welcome changes and technical excellence

5. CONCLUSION

This paper covers questionnaire surveys data collection and analysis distributed among professionals in both software and construction industries to obtain their opinions and answers regarding this research. The results are analysed and compared with other researches to validate objectives of this study. This type of the survey included general questions about agile, BIM and traditional project management approach. The results supported effectiveness of agile to manage construction projects. Also, professionals agreed with BIM effectiveness in collaboration and coordination between multiple disciplines during design and construction stages.

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An Exploration of the Potential for Using Modular Housing Solutions to Address the UK's Housing Shortage

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Abstract

The UK construction industry is affected by a shortage of affordable housing exacerbated by a shortage of skilled labour. This paper explores opportunities to use modular homes to address the UK's housing shortage. In developing this paper, a questionnaire-based survey was undertaken following a literature review. The survey of industry professionals involved 70 structured questionnaires sent online. The study revealed that one of the most pressing issues within the housing industry is the lack of affordable new developments. Again, a lack of investment in apprenticeships has led to skilled trades shortages in the industry. The study found that modular homes would provide would produce homes quicker and cheaper. Other benefits of modular housing are the use of eco-friendlier materials, waste reduction and reduced CO_2 emissions from construction processes and from reduced transportation. Reduced maintenance requirements also reduced life-cycle costs however traditional housing was seen as having a longer lifespan. Due to restrictions in place at the time relating to the COVID 19 pandemic, detailed confirmatory interviews could not be conducted. This could have provided some additional insights into the general trends arising from the survey. Further research could investigate the costs associated with contractors establishing their own manufacturing facilities as a means to reducing the time and costs for offsite manufacture of construction components. Future research could also explore the potential of increased integration of Value Engineering and Building Information Modelling (BIM) into modular house building and the evaluate the potential benefits.

Keywords
Modular, Housing, offsite-construction, skills shortage, construction

1.0 Introduction

The construction industry contributes to nearly £117 billion pounds to the UK's economy, 6% of the total revenue with the industry responsible for providing 2.4 million jobs in the UK making up 6.6% of all jobs (Rhodes 2019). Due to the ever-growing population across the UK and the rest of the world, there has been an increasing argument for the countries housing shortage and the unavailability of homes needed at an affordable price for first time buyers and young families. These current challenges are creating pressure on house builders to change the way in how builders develop (Zandari & Hashemi 2017).

In 2014, the UK house prices were valued at the second highest in the world when measured at a price per square meter (Hilber 2015). According to Marshall Recruitment (2019), statistics showed that the "price-to-income" multiplied by salary in the greater London area was around 8.5 times the average salary. Furthermore, the rest of the UK found that property prices had increased as much as 5 times the average income for a property. The UK house price growth over the past 40 years has increased faster than any other Organisation for Economic Co-operation and Development country (OECD) and has outgrown earnings. This has consequently produced a housing affordability crisis. As well as the increase in house prices throughout the UK, the housing unit sizes are a considerable amount smaller than in comparison to other European countries (Hilber 2015). Hilber (2015) provided statistics that the UK currently produce homes at around 38% smaller than Germany and a further 40% smaller than the Netherlands (Statistics Sweden 2005). Approximately the number of homes needed in England are up to 345,000 per year (Wilson & Barton 2020). Back in 2018/2019 the total amount of homes in England increased by around 241,000 homes providing a 9% productivity increase than the previous year although still lower than the estimated quantity needed. The current skills shortage is believed to be holding back efforts to resolve the housing crisis and the number of homes that are built. With around 87% of construction companies looking to expand producing around 100,000 vacancies, one in four (24%) of housebuilders explain that finding skilled trades are becoming the largest challenge (Owen, 2015). Furthermore, the UK workforce isn't getting any younger with the Office for National Statistics (ONS) revealing that 20% of construction workers are over fifty with 15% being over sixty (Marshall Recruitment 2019).

In this context, modular housing has been hailed with the government and the construction industry suggesting that, modular homes could be the answer in resolving the housing shortage and the skills shortage. Modular homes will provide a cheaper option also removing the need for as many skilled workers due to the units being constructed in quality-controlled factories off-site. This paper explores the opportunities to use modular construction solutions to address the housing deficit and the opportunities this will bring.

2.0 Literature Review

2.1 Modular Homes

Modular construction is a system that is pre-assembled and constructed in a factory consisting of a lightweight, load-bearing composite panels that are used to form the walls, ceilings and roofs of a structure (Glenn Low 1987). Lopez & Froese (2016) define modular housing as *"housing that is partially built in a plant, shipped to a development site, and placed on a foundation, where the roof structure and exterior finishes are completed"*. Modular homes are cost effective when comparing to conventional homes due to being built in a factory environment that provides ideal production conditions compared to site construction (Lindal 1982). Modular construction has established a strong market in residential buildings due to the speed benefits, quality and cost savings that are achieved (Lawson 2010). This system of construction uses an inside out approach completing the interior surface, electrical, plumbing, mechanical fixings before completing the exterior. This differs from the traditional on-site assembly sequence constructing from the outside in (Ferver 1980).

Manufactured construction, off-site construction, off-site manufacturing, industrialised building systems and modern methods of construction are all generic terms used interchangeably in extant literature to describe modular construction (Goulding *et al*. 2012). The underlying idea involved in all these concepts is that some activities relating to construction projects are moved away from the construction site into controlled factory environments within manufacturing establishments (Jaillon & Poon 2010). These are described in some literature as a panacea to the many problems associated with cost, time and quality associated with traditional construction processes (Goulding *et al*., 2013).

2.2 UK's housing affordability crisis

The UK is currently in a housing crisis and despite the rapid increase in housebuilding, the UK house prices have grown by 160% since 1996 (Dmitracova 2019). Ferguson (2016) though states that the average house price has increased significantly more risen to an extraordinary 281% across the UK with statistics showing that London figures have increased a further 501% (Nationwide house price index). The reason behind the increase in property value is down to the lack of available homes therefore increasing the demand (Hall 2020). Hall (2020) goes on to explain that:

"When there is a high demand for a good or service, its price rises. If there is a large supply of a good or service but not enough demand for it, the price falls".

In 2014, UK house prices were the second highest in the world, only topped by Monaco with house price growth increasing faster than any other OECD country (Hilber 2015). Since the late 1990's, the mortgage rates have tumbled with interest rates being fixed on a five-year-fixed-rate term. One of the many issues causing the housing crisis is the average earnings to house cost ratio. Currently, the UK house now costs almost eight times the average salary with banks and building societies typically lending people a maximum of four and a half times individuals income (Chu 2018). Because of this, the home ownership has slumped to 63% due to the soaring house prices relative to earnings (Independent 2018).

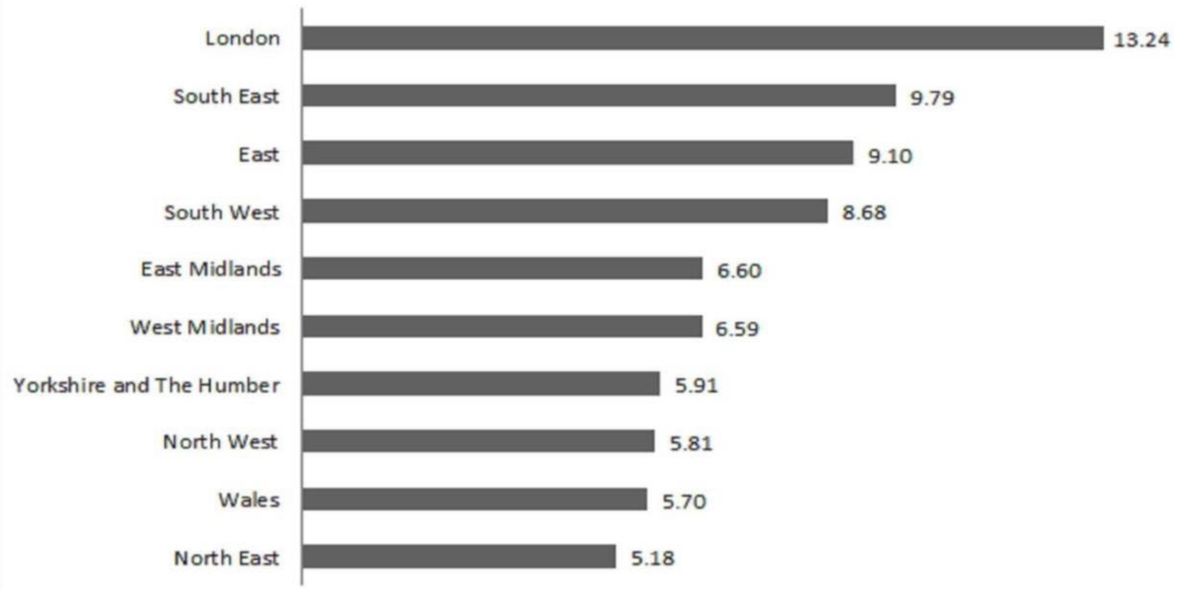

Figure 1 2017 House prices to earnings (Marshall Recruitment, 2019)

2.3 UK's Current skills shortage

Lloyds Banking Group believes that skills shortage and planning systems are preventing solutions for the housing crisis. A severe shortage of skilled workers in the housebuilding industry are hindering efforts to tackle the UK's housing crisis (Flockhart 2016). It has been reported that the current UK construction workforce is too small to meet with the UK Governments housing demands.

In 2017 the government had pledged to develop 300,000 new homes a year by 2020. A massive concern to this is that RICS have confirmed that a shortfall in skilled construction workers in the UK is currently at its highest point since 2007 (RICS 2019). According to the (CIOB) the industry must employ over 150,000 new workers by 2021 in order to keep up with the demands from the Government. Light (2017) disagrees by suggesting that Britain actually need a considerable amount more estimating that around 400,000 people each year must be recruited providing an equivalent statistic of one person every 77 seconds.

Approximately 87% of construction companies plan to increase their companies yet while all these vacancies are becoming available, 24% of housebuilders have confirmed that finding the candidates with the appropriate skills are becoming "the biggest challenge" (Owen 2015). It is evident that the lack of skilled trades is causing huge disruptions to the housing shortage and that moving forwards, the Government must invest into training schemes and apprenticeships to offset the reduced number of skilled professionals in the industry.

2.4 Affordability of Modular housing

In recent years due to the industry unsuccessfully supplying enough homes to keep up with the increase in population, a growing interest in the modular construction industry from both investors and developers have been the main topic (Lopez & Froese 2016). Modular homes are offering several benefits over traditional. Some of the advantages are a reduction in construction time due to the units being constructed in a factory, high quality as the factories are quality controlled and cheaper costs providing financial saving for suppliers and buyers reducing property prices.

Modular construction has long been developed and used in the construction industry within residential as a means of a quicker production supply and a quicker turn around (Velamati 2012). Mass production could allow new homes and apartments to be radically cheaper due to the design behind modular construction (Barnett 2018). Some experts believe factory-built properties could resolve the housing crisis due to mass production opportunities and better quality control provided by factory conditions.

2.5 Modular Construction impacts on skills shortage and productivity

Modular housing can address the skills shortage and tackle the domestic sector (Sean et al. 2015). The UK have an ageing workforce with 12% of construction workers under the age of 24. With the lack of skilled workers in the industry and the lack of skilled trades coming through the apprenticeship scheme, the means for modular housing will help solve the UK's skills shortage. The Government in 2015 expressed concerns about the lack of training stating that, *"structure of industry training is not sufficient to deliver the skilled workforce required to build enough adequate housing"* (Wilson & Barton 2020).

Modular construction will reduce the need for large amounts of skilled trades and will provide a lower skill demand due to houses being factory built. Traditional methods of construction will demand a high number of onsite skills that the industry lack although by transferring to modular methods of construction, 90% of activities will be completed prior to site delivery. Off-site manufacturing can attract and develop non-skilled resources throughout the industry without relying on limited skilled resources (KPMG 2016). In addition, modular construction will address the skills shortage and allow the government and developers to continue developing the despite the increase in the skills shortage. Off-site construction will offer the opportunity to speed up the delivery of new homes and will allow projects to be delivered on time or earlier by around 50% (Construction news 2016). There is evidence to suggest that schedules can be saved by almost 60% when comparing to traditional methods of construction.

Banks *et al*. (2018) presents a 40-storey mixed-use development in central London, UK which successfully employed the principles of DfMA across all engineering disciplines for the project. In this project, the delivery team developed effective off-site construction solutions across the entire project including the superstructure, facades, bathrooms and mechanical and electrical services. These were all designed, coordinated and facilitated using DfMA through advanced digital engineering and building information modelling techniques. According to Banks *et al*. (2018), the project was delivered with reduced programme and cost with an improved safety record, higher quality and reliability in a more sustainable way through reduced vehicle movements and a greater efficiency in the management of site logistics.

2.6 Limitations of Modular Construction

Modular homes are designed, manufactured and preassembled off-site before being transported to its final location (Warszawski1999). Although modular construction comes with many benefits there are also limitations and disadvantages. Taylor (2010) explains that modular homes are limited when creating the floor plan because of transportation from the factory to site. Modular homes have a width of no more than 14 to 16 feet although can be 60 to 70 feet in length (Warszawski 1999). Taylor (2010) goes on to suggest that it's not feasible to deliver the modular homes very far due to the road size restrictions. Due to delivery playing a key role into transporting the modular home to its final location, contractors must consider transport limitations. These limitations can be time delays, permits needed due to oversize vehicles, and dimensional limitations.

Golawski (2018) points out that there are no design limitation preventing modular methods although BONE (2016) argues this by suggesting that modular methods will only provide a limited number of materials and layouts because of the factories mass production. Gassett (2015) agrees by confirming that modular homes lack customisation, and that design is limited. Project planning is another key factor producing yet another limitation. Sites in Japan, USA and Sweden have come across problems where clients would like to apply a variation in the scope of works and unlike traditional, modular construction has proven to be much more difficult when alterations are need (Kamali & Hewage 2016). Kamali & Hewage (2016) argue that modular homes provide a high initial cost and that although this method of construction is cheaper, a considerable amount of capital is initially needed when purchasing these products. The reason behind this is that modular homes are built and completed in a factory before transported to its final destination therefore supplies demand an upfront cost before purchase. Lynn (2017) opines that pre-manufactured homes provide a financial economical solution to the housing crisis. This is because of the reduction in labour costs and materials. The ready-built factory units reduce the need for the skilled trades and the materials wastage is heavily reduced due to machines producing the sufficient amount of material needed.

3.0 Research Methodology

This paper is based on a detailed review, critique and analysis of contemporary extant literature on the subject. Following the review, a questionnaire-based survey was used to collate views of industry stakeholders in relation to modular construction. This Literature review was based on of industry books, academic journals and scholarly reports that provided the secondary data (Naoum 2013) which provided also provided a basis for the development of the survey instrument. The survey provided the perspectives of respondents and helped to better understand their perceptions of how the UK can implement this method of construction and it potential to help resolve the current housing crisis that affects the UK

Owing to the prevailing restrictions on movement at the time of the survey, questionnaires were administered online using a survey tool called Sogosurvey. This online platform allowed the dissemination of questionnaires to respondents and their collation once completed. Once all the data was collected, Microsoft excel was used creating table and charts showing the results identifying.

4.0 Findings and Discussion

Evidence from the review of literature confirmed that the many acknowledged benefits of modular construction would enhance the application of modular approaches in housing developments. Amongst the many benefits included speed of construction, reduced costs, quality of construction and reduced life-cycle costs. Despite the proven benefits, there were limitations associated with their use such as higher initial costs, industry aversion to the technology negative perceptions associated with the technology.

A total of 70 questionnaires were sent out with 56 responses providing an 80% feedback response. All the data was collected and assessed analysed using simple statistical analysis of the respective percentages and averages. Respondents in the survey consisted of 7% Architects, 21% Surveyors, 7% Designers, 9% Project Managers, 5% Company Directors, 2% Planners, 5% Estimators, 13% Site Managers, 7% Contract Managers, 20% Contractors and 4% Clerk of Works. The results provided show that the most common sector that undertook the questionnaire were individuals that worked within commercial with a percentage of 46%. The data received also indicated that the majority worked for main contractors with a figure showing of 54%.

Of the respondents, 5% had a master’s degree, with a further 9% achieving a professional qualification. 37% achieved a bachelor’s degree, 21% gained an HND/HNC, 7% achieving A-levels and 19% completing a City and Guilds. Generally, therefore, the respondents comprised of a high proportion of professional level industry stakeholders with a good level of professional and technical knowledge of construction.

The results showed that 45% “strongly agreed” or “agreed” with modular construction having a good potential to become an alternative to conventional building methods with 30% disagreeing whilst 25% were unsure. This shows that whilst a majority see the potential of modular housing solutions, the proportion of stakeholders in the industry who are yet to be convinced is still significant.

On the potential benefits of modular solutions in the housing sector, 29% of respondents suggested that the overall speed of constructing the homes would increase providing better production levels. A further 25% believed that the materials provided for the modular homes would be eco-friendlier with another 20% stating that waste reduction levels would be significantly reduced as the pods are built in controlled environments. 16% explained that transportation emissions would be reduced due to majority of materials used being from one factory. The remaining 10% of respondents highlighted the thermal insulation benefits that modular would bring to the industry. The small relative percentages who advocated these benefits may explain the hesitancy that exists in the industry in relation to the uptake of offsite techniques. This demonstrates that additional sensitisation and education for industry stakeholders on the potential benefits of modular techniques would help. On the prospects of modular housing becoming the mainstream method of construction in the housing sector in the future, 50% of respondents agreed with the prospect with 18% disagreeing as shown in figure 2. This shows that whilst a larger overall percentage of respondents see the potential imminent increase in the adoption of in modular solutions in housing, this is not necessarily backed up by an awareness of potential or proven benefits.

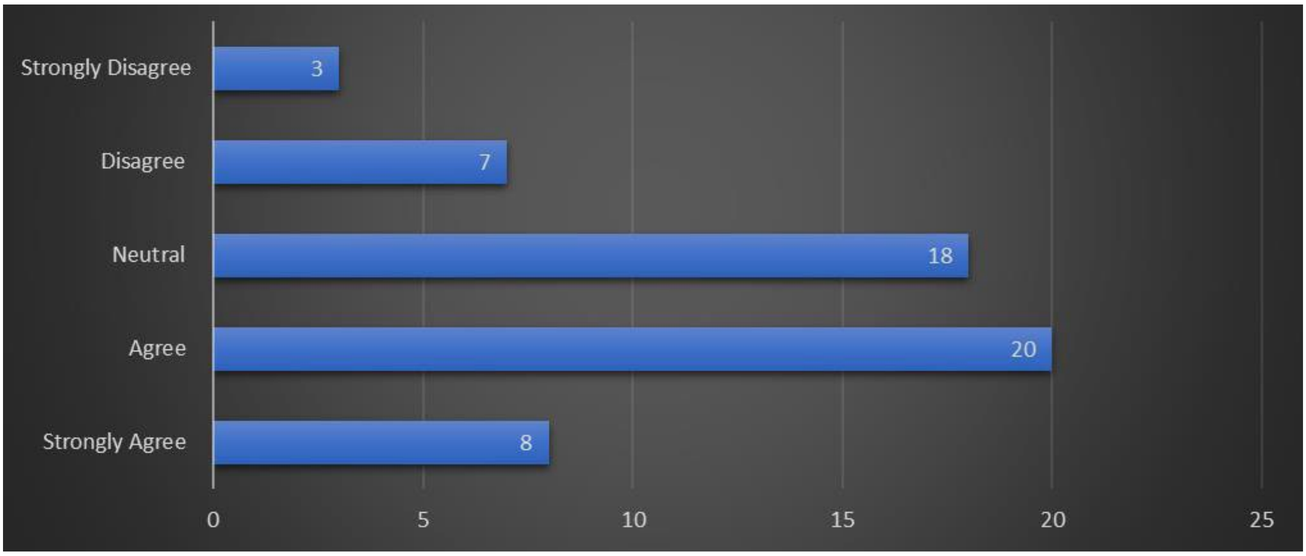

Figure 2 Potential of Modular Housing as Main Approach to Housing Development

5.0 Conclusions and Further Research

This study revealed that the current issues within the housing industry is the lack of new developments that are being built and the affordability for current dwellings. The housing crisis has affected an estimated 8.4 million people living in England. Another factor that this study revealed is that the population has outgrown the construction industry with around 3.6 million people living in an overcrowded home. Furthermore, due to the lack of investment in apprenticeships over the last 20 years contractors are now struggling massively to employ skilled trades to complete the jobs. All these factors have caused the current outcome with the objectives and learning outcomes being supported with the data gained from the questionnaire and interviews that had been completed.

The paper identified benefits of modular housing to include speed of construction, eco-friendlier materials, waste reduction and reduced CO2 emissions from construction processes and from reduced transportation. The overall proportions of the respondents who identify with these benefits are generally low, which suggests overall low levels of awareness of the potential benefits that offsite solutions present.

The study also identified modular homes as having the potential to provide cheaper housing options. Reduced maintenance requirements also reduced life-cycle costs however traditional housing was seen as having a longer lifespan.

Despite the acknowledged benefits and the opportunities presented by modular housing solutions, the numbers of respondents who demonstrate an awareness of the potential and the benefits of modular solutions in housing are relatively low. This points to a low level of awareness of the potential benefits that modular solutions offer and a weak understanding of the associated benefits. Industry-wide educational efforts in this regard will be beneficial.

Further research could investigate the costs associated with contractors establishing their own manufacturing facilities as a means to reducing the time and costs for offsite manufacture of construction components. Research could also explore the potential of increased integration of Value Engineering and Building Information Modelling (BIM) into modular house building and the evaluate the potential benefits.

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Efficient Utilization of Public-Private Partnerships (PPPs) to Develop Resilient and Sustainable Public Infrastructure

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Abstract

The efficient utilisation of long-term public-private partnerships (PPPs) contractual models for the procurement and operations of public services and infrastructure has been a widely debated topic within the infrastructure industry and the academic research. Whilst the key driver for PPPs remains to be the public deficits facing critical infrastructure requirements crucial for both current public needs and future economic growth, the socioeconomic benefits have been historically marginalised. This paper examines the global and the regional landscape for achieving socioeconomic benefits under PPPs and the associated contribution to the national development agenda in alignment with the global pledge to develop sustainable and resilient infrastructure under the umbrella of Sustainable Development Goals (SDGs). The paper is based on the researcher's master thesis This where the research approach follows Conceptual Framework of an exploratory Study of existing literature and semi-structured interviews followed by case study research. This paper concludes that incentivised output-based performance PPPs can drive the private sector to achieve optimum efficiency through utilising the best of its experience and innovation to maximise efficiency gains incentivised by revenue sharing or rewarding schemes whilst concurrently delivering socioeconomic benefits contributing to the economic growth and quality of life, conditional to identifying the targeted socioeconomic outcomes at the earlier preparation stages and specified within the contractual agreements e.g. reduced service tariff, improved service quality and coverage, service reliability and availability and moreover, employability and income.

Keywords
Public Private Partnerships (PPPs), Sustainable Development Goals (SDGs), Sustainable Cities

1 Introduction

Efficient infrastructure programmes are the foundations for long-term development, decreasing inequality and unemployment and strengthening sustainable growth. Across most developing and developed countries, infrastructure needs significant improvement, as does its financing ability. It is estimated that the worldwide infrastructure financing gap of around US$1trn per year, representing 1.4% of GDP. (World Economic Forum 2016)

Across the developing world, public budget as the largest contributor of infrastructure finance have not fully recovered from the last financial crisis, widening the market for infrastructure finance. Traditionally, governments have burdened the major share of infrastructure finance with tax revenues. As most the demand for infrastructure for most countries increases, Public-Private Partnerships (PPPs) perform a significant role in delivering public assists and services, thus narrowing the infrastructure gap.

In a broad way, PPPs can be viewed to cover the integration between the public and the private sectors and specifically sets of financial and risk-sharing relationships. Even when viewed closer, the number of PPPs is already significant in some countries and in majority of countries the number of new PPPs is increasing. PPPs contributed for US$90.7 billion (290 Projects) billion of the total US$93.3 billion (304 projects) for Private Participation in Infrastructure (PPI) in low- and medium-income countries in 2017 (World Bank Group 2017).

If utilised efficiently PPPs can provide better value for money than traditional procurement, however, they can be threatening for the fiscal sustainability due to the complexity of the aspects of risk sharing, affordability, costing, contract negotiation, budget and accounting treatment. Moreover, the impact of the PPPs has been historically to a degree limited to the impact on the capital and operational expenditure without the comprehensive consideration of the wider socioeconomic impact especially in low- and medium-income countries where PPPs are politically and fiscally driven. The academic empirical literature is very limited. Most evidence is based on informal and unreliable case studies and evidence. Moreover, most case studies are comparing outcomes after and before without well-defined parameters where the overall socioeconomic impact has not been comprehensively analysed using robust analysis. (World Bank Group 2016)

The argument about the inefficiency of PPPs and the effectiveness of the evaluation methods, will be explored through this paper to determine the current significance of Private Participation in Infrastructure (PPI) after decades of utilising PPPs across the world, and the wider socioeconomic impact. Moreover, the dissertation will test the maximisation of the efficiency gains through incentivized output-based performance utilising the foremost of the private sector expertise and innovation to achieve the optimum value for money concurrently with delivering predetermined socioeconomic outcomes.

This paper will test the hypothesis "**Public-Private Partnerships should be structured as socioeconomic partnerships to drive optimum value for money concurrently with socioeconomic outcomes through incentivized output-based performance**" *where the research approach follows three principal stages; (1) exploratory study to identify concept, (2) case study research to test the identified concept empirically and finally (3) review of secondary sources to confirm the empirical results of the case studies research on a wider scale.*

This study will explore the socioeconomic impact of successful PPPs based on output-based performance agreements, and the ultimate benefits during efficiency gains during the long term operational stage rather than the focus cost and time efficiencies during construction stage only.

2 Literature Review

This section will review the existing literature about PPPs, and it is structured as following (1) Existing Literature, (2) Lesson Learnt, and (3) Research Motivation and Objective.

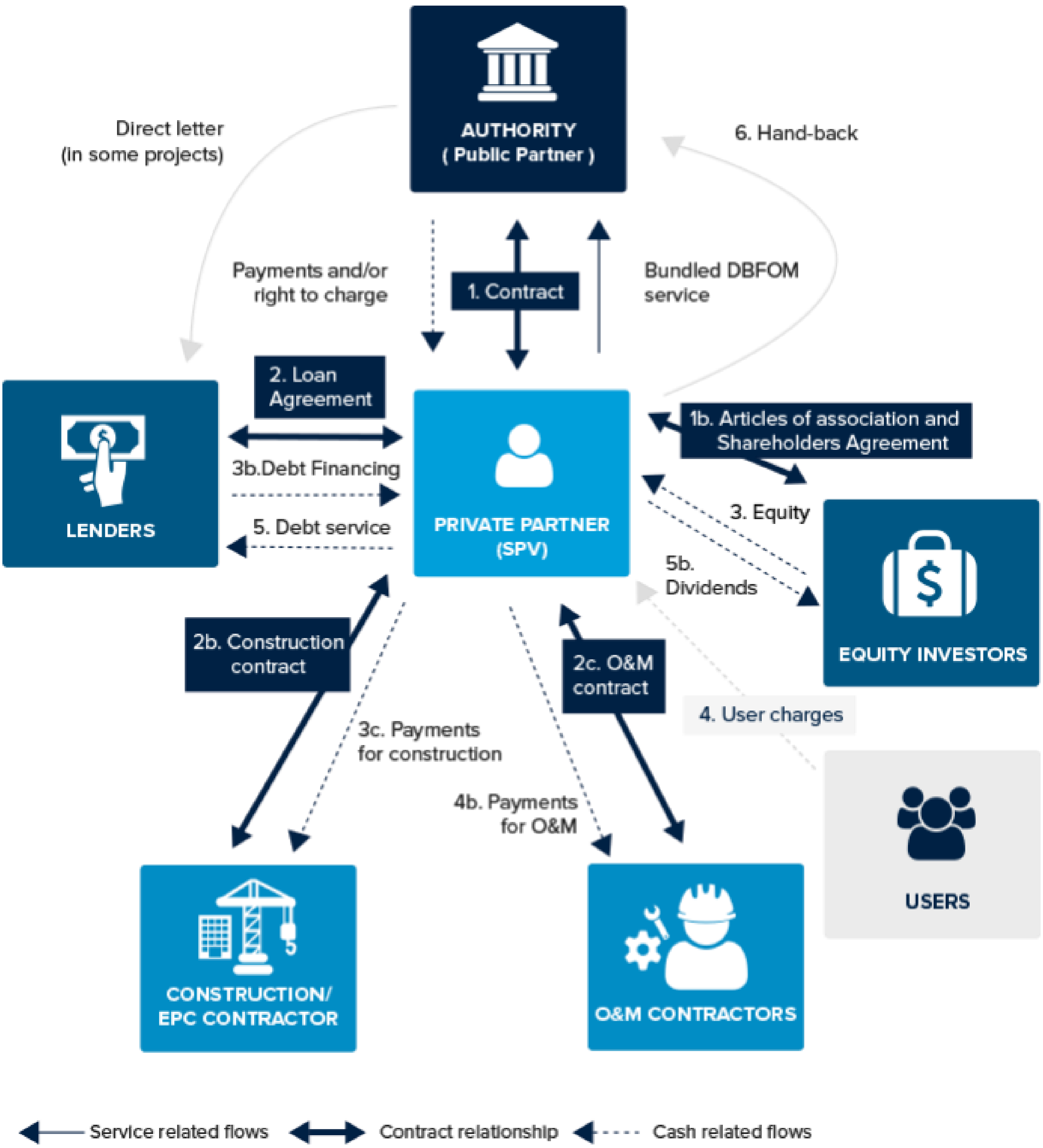
This section represents the theoretical base for the hypothesis. It provides crucial background knowledge and foundation for the discussion of the conceptual framework and demonstrates how this study can contribute the body of knowledge.

2.1 Existing Literature

There is no universal definition for PPPs where each international organisation and government authority has developed its own definition, for example; OECD defines PPP as "An agreement between government and one or more private sector partners (which may include the operators and the financers) according to which the private partners deliver the service in such a manner that the service delivery objectives of the government are aligned with the profit objectives of the private partners and where the effectiveness of the alignment depends on a sufficient transfer of risk to the private partners" (OECD 2008) whilst UK defines a PPP as "arrangements typified by joint working between the public and private sectors. In their broadest sense, they can cover all types of collaboration across the private-public sector interface involving collaborative working together and risk sharing to deliver policies, services and infrastructure." (HM Treasury 2008).

There is no standard contractual form for PPPs where the contractual structure is shaped upon the objectives of the project. However, there are some common types of contractual structures for PPPs i.e. long-term performance-based Management Contracts, Design-Build-Finance-Operate-Maintain (DBFOM) and Built-Operate-Transfer (BOT).

The diagram below illustrates the relationships between the different parties within the contractual structure of a typical PPP and the associated responsibilities



Note: DBFOM=Design-Build-Finance-Operate-Maintain; EPC=Engineering, Procurement, Construction; O&M= operation and maintenance; SPV= special purpose vehicle.

Source: APMG CP3P Certification Guide 2016

Payments under PPP contractual structures is divided principally into two mechanisms; (1) User-pay concession PPP – payments are received directly through the revenues from end-user payments.

Demand risk is the principal concern for such arrangement. An example is toll-road PPPs; and (2) Government-pay PPP – payments are principally received through the government. Sometimes known as availability pays PPP as the payment takes place when the asset is available for use regardless the performance levels.

This section explores the key rationale for using PPPs in the financing and development of public infrastructure and services as demonstrated in the existing academic literature and industry reports. It widely agreed that there are 4 principal key drivers for using PPPs; (1) infrastructure finance gap (2) alternative finance to restrained public budgets, (3) inefficiencies of the public sector, and finally (4) efficiency of the profit-driven private sector.

Across the developing and developed countries, infrastructure needs significant investments for development, maintenance and rehabilitation which can`t be fully financed through the strained government budgets where governments are seeking alternative finance through the private sector to reduce the infrastructure finance gap and avoid restricting the associated economic growth. The global infrastructure finance gap has been estimated at 1 billion USD annually representing 1.4% of Gross Domestic Product (World Economic Forum 2016)

Investment in the development of existing and new public infrastructure is always strained due to limited government budgets. This delay affects the economic growth, which is significantly supported by the infrastructure development, and moreover, the delay threatens the quality of life of citizens due to the deterioration of level of services. (Agrawal 2010). “One significant motivation in using PPP has been to partly overcome budget and borrowing constraints, which have become a major restriction of national policy autonomy” (McQuaid and Scherrer 2008)

As a general logic, the experience of private sector surpasses the public sector, a government agency would be limited to a few number of similar type projects and within certain geographical jurisdiction while the private developer would be continuously developing similar type projects in various locations harvesting significant experience of defaults and lessons learnt motivated to increase efficiency, and thus maximising the profits. In addition to the full life cycle approach for long-term concessions where the asset is designed or rehabilitated at the early stages of the contract to provide ultimate efficiency along the life cycle to maximise operational savings and the associated profits. Risk management is the core foundation for the various efficiency gains in PPPs.

A fundamental concept in PPPs is that each risk should be allocated to the party best able to manage and mitigate this risk. For the public sector, risk transfer provide certainty on cost and time, and moreover reliability on outputs where any default is highly penalized where for the private sector is rewarded for the transfer of this risk in a fair trade-off of risk and reward that drives higher efficiency and savings. A principal motivation for PPPs is the cost and time efficiencies compared to the traditional procurement. The cost of public procurement in its pure nature without private sector profit under lower interest rates for debt should be cheaper than the private sector, only with efficiency gains, the private sector can driver better value for money. In a study that explored the performance of completed PPP projects compared to traditionally procured projects, it was concluded that PPPs provided significant reductions in cost and time overruns. (OECD 2011). Similar results were achieved on high cost and time efficiencies in Australia (Raisbeck et al. 2010). Another study for North America confirmed the cost and time efficiency gains (Chasey et al. 2012).

Infrastructure is the core foundation for socioeconomic progress. “Infrastructure typically has a socioeconomic rate of return of around 20 percent. In other words, one dollar of infrastructure investment can raise GDP by 20 cents in the long run” (Mckinsey Global Institute 2016). This economic impact is a result of enhanced productivity through reduce service tariffs and improved quality, moreover, smart infrastructure upgrades connect the countries to the global digital economy. In addition, infrastructure increases employability and creates jobs. "In the shorter term, increasing infrastructure investment by one percentage point of GDP could generate an additional 3.4 million direct and indirect jobs in India, 1.5 million in the United States, 1.3 million in Brazil, and 700,000 in Indonesia" (Mckinsey Global Institute 2016).

However, the academic empirical literature is very limited. Most evidence is based on informal and unreliable case studies and evidence. Moreover, most case studies are comparing outcomes after and before without well-defined parameters where the overall socioeconomic impact has not been comprehensively analysed using robust analysis. (World Bank Group 2016).

2.2 Lessons Learnt

Public infrastructure projects are complex arrangements that requires large investment and has a significant impact on the economic development and quality of life. It is crucial to learn from past experience to deliver major infrastructure projects efficiently. "Learning is expected to improve the generation and utilization of useful knowledge to help governments avoid future policy failures and increase the potential for greater success with respect to future policy goals and outcomes" (Howlett 2009). Failure can be caused by inability to learn from past experience to enable future success in identification and mitigation of unforeseen risks and avoidance of poor implementation.

Many of the developed countries have seen the benefits of concluding and extracting the lessons learnt from past experience in order to enhance policy, legislation and implementation of PPPs. However, the assessment of the performance and impacts of completed PPPs on the efficiency and quality is limited. Some studies include partial assessments with a more comprehensive assessment for PPPs in OECD countries. This section will demonstrate the conclusion of the lessons learnt from a number of reputable international organisations, financial institutions and national government that have led a significant number of PPPs in major infrastructure projects.

In 2014, WBG investigated the performance and efficiency of PPP framework through reviewing the performance of 60 PPP projects in 35 countries along the period of 7 years, projects worth more than $10 billion and providing service to more than 30 million people. All selected projects included the delivery of public services with some risk transfer to the private partner. Lessons learnt are divided into 3 main categories economics, politics and execution which are the main drivers for the success or failure of PPPs. This section will focus on the economic and political factors considering their relevance to the research topic.

- Economics – PPPs can improve challenging project economics, only if sound economic fundamentals in the terms of robust basic cost assumptions and a coherent business case are considered. PPPs should structure partnerships that balance the economic benefits of the private partner and social outcomes of the public partner driving optimum cost, quality and investor return. (World Bank Group 2014)
- Politics – Political champions play a crucial role in the success of PPPs especially public-sensitive sector as education, healthcare and aviation. In addition to the need for long-term consistent and sustainable regulatory framework for PPP programs and pipelines that aren't affected by the regular change of political systems. Stakeholders in general are influential to the success of PPPs due to the various socioeconomic and environmental impacts and concerns which should addresses at the very early stages of the project with maintaining efficient stakeholder management. (World Bank Group 2014)

In 2009, EIB investigated the performance of 66 active PPPs and concluded the lessons learnt as following:

- Two major threats identified by the participating interviewees are the political motivationand off-balance nature of PPPs that leads to the implementation of PPPs in countries that can`t afford them.
- Robust project screening process and coherent pipeline of projects supported by transparent procurement process, are among the crucial success factors for PPPs.
- Significance of the proper management and mitigation of project risks as well as demand risks.

2.3 Research Motivation and Objectives

The existing literature of studies and industry reports demonstrates the significance of social and economic factors on the success of PPPs, and its influence on the value for money evaluation. However, the review of the existing literature about PPPs has identified the lack of research on the socioeconomic impact of PPPs and the distant consideration in the VFM analysis specifically in low and medium income countries where PPPs are political driven focusing on the short-term development of the capital asset.

Most economists and practitioners agree that the main benefits of PPPs are maximizing efficiency gains. However, the findings in the literature are less clear on socioeconomic outcomes in terms of job creation and poverty reduction as they seems to be linked to the provision of infrastructure services itself rather than the procurement method used (traditional procurement vs. PPPs).

The academic empirical literature of the economic impact of PPPs is very limited. Most of the evidence is based on anecdotal evidence and case studies with the majority of them comparing outcomes before and after without a well-defined counterfactual.

Sound empirical analysis has been carried out in the literature of private sector participation (PPI) in Infrastructure mainly privatizations. (Galal et al 1994; Jones et al. 1998)

The identified research gaps within the existing literature of academic research and industry report concerning the socioeconomic impact of PPPs and evaluation of whole life cycle costs, raises two significant research questions that can contribute to the body of knowledge for the successful implementation of PPPs;

“Can PPPs drive optimum value for money through incentivized output-based performance efficiency gains across the lifecycle of the asset, standing out from traditional procurement?”

and

“In the pursue for a better value for public money, can PPPs deliver tangible socioeconomic benefits?”

This paper will test the following hypothesis about the structure of successful and efficient PPPs **“Public-Private Partnerships should be structured as socioeconomic partnerships to drive optimum value for money concurrently with socioeconomic outcomes through incentivized output-based performance”.**

This research will contribute to the literature addressing socioeconomic impacts of PPPs and the significance of incentivized output-based performance compared to traditional procurement to maximise efficiency and value for money.

3 Research Methodology

This section demonstrates the methodical approach to select the research philosophy and strategy that will be used to test the research hypothesis and answer the research questions where the conceptual and case study approaches are the recommended research approached due to the complex nature of the output-based performance and the associated socioeconomic impact.

The review of the existing literature of academic research and industry reports in the previous chapter suggests the importance of understanding and analysing the overall context of PPPs to determine the success factors and the outcomes of output-based performance and the associated socioeconomic impact.

“Empiricism is referred to as a set of philosophical beliefs that have developed upon the idea that experience, rather than reason, is the main source of the knowledge of the world” (Morick 1972). The research based on empiricism is a practical method to investigate the nature of the world through ways that depend on experience rather than assumptions and theories. Empirical research settle questions about the nature of human ideas and actions by recognizing claims raised by direct observations only (Love 2001). Discussion and arguments can drive important concept. “The interpretivist approach focuses on selecting what data should attend to imply ‘theory’. The belief of interpretivism relating to ontology and epistemology is that realities are multiple and relative” (Hudson and Ozanne 1988).

The conceptual framework for this research is incorporated by contextual factors from the literature review. The conceptual framework guides the requirements from the empirical data to test the research hypothesis and address its questions. In this dissertation, sequential triangulation was the basis of the research design which has been a widely endorsed approach in both of natural and social sciences. In this thesis, the research design was based on ‘sequential triangulation’. It is notable that the triangulation approach has been advocated by researchers and widely applied in a variety of studies for both social and natural sciences (Morse 1991; Love et al. 2002; Bjurulf et al. 2012).

The research approach includes three principal stages; (1) exploratory study to identify concept, (2) case study research to test the identified concept empirically and finally (3) review of secondary sources to confirm the empirical results of the case studies research on a wider scale.

This research is investigating multifaceted phenomenon to develop a deep understanding of the context which can be achieved through case study research (Eisenhardt and Graebner 2007). One of the main strengths of case study research is comprehensive analysis of real life events which strengthened our knowledge of organisational and individual phenomena which differentiates case sturdy research from experiments and surveys due to their limited ability to explore wider context (Yin, 1994). Moreover, the conceptual framework through its exploratory study is used to direct data collection and analysis within case study research.

4 Findings and Discussion

4.1 Exploratory Study

The exploratory study undertaken is based on an interpretivist approach that depends on semi-structured interviews to extract the required primary data to test the hypothesis derived from the literature review. It has been demonstrated in the previous sections that researchers in performance measurement researches tended to "marry with the ontology and epistemology of interpretivism because reality and multiple perspectives are sought to gain an understanding of its use in practice" (Neely et al. 2000).

For the purpose of a comprehensive research on output-based performance measurement of PPPs and the associated socioeconomic impacts, a qualitative study was undertaken to investigate the current practices and outcomes.

To meet the objectives of the interpretivist research, it requires "the purposive selection of a sample size of 10 to 35 participants who have specialised knowledge of the topic" (Kumar, 1989). Accordingly, the researcher conducted 17 in-depth interviews with market leading experts who were directly involved in preparation and implementation of PPPs in the Middle East and/or globally, and thus acknowledged as experienced practitioner in the PPP industry.

The interview questions focused on the topics that can contribute to interpretation the research area and testing the research hypothesis. These topics included; (1) significance of PPPs in Public infrastructure, (2) motivations and obstacles, (3) socioeconomic parameters in the evaluation of PPPS, (4) relationship between output-based performance and efficiency gains, and finally (5) relationship incentivized output-based performance and maximizing efficiency gains.

There is a general agreement from the interviewed experts from various sectors of the infrastructure industry on the significance of PPPs in the finance and development of infrastructure. Majority agreed that in addition to the infrastructure finance gap, one of the main drivers of PPPs is inefficiency of traditional procurement through raising debts and awarding separate contracts with fragmented lifecycle between design, construction, operation and maintenance, and ultimately disconnected from output-based performance of such contracts.

On the wider impact of PPPs, majority of experts agreed that efficiency gains of PPPs should have a wider socioeconomic impact through the efficiency gains achieved. The experience and the efficiency of the private sector should be used to improve the quality, reliability and coverage of the public services, moreover, the impact should be reflected to the economic prosperity of the surrounding areas to these projects in terms of increasing productivity, reducing tariffs and employability on the long run. The main challenge that has been highlighted is the balanced distribution of the efficiency gains between the private sector with profit driven and the public sector which social-driven which can be only achieved through well-structured output-based performance contracts for these complex projects determining output obligations and the associated profits. Moreover, whilst being of utmost importance, integrating the stakeholder aspect into the overall PPP scheme has shown to be challenging – not in the least because of the soft, subjective and non-measurable aspect of it.

On incentivized output-based performance, there is a general agreement that this approach leads to the ultimate efficiency gains rather than fixed output levels obligations. However, the complex nature of these projects remains the biggest obstacle especially from the perspective of the demand risk and revenue sharing.

4.2 Multi-Case Study Research

This section presents a number of success and failure stores for the utilisation of PPPs in the financing and development of public infrastructure within the sectors of transportation, water and telecom which were used to empirically test the output-based performance of PPPs compared to its preceding performance under traditional procurement, and the associated socioeconomic benefits.

4.2.1 Success Stories in PPPs

This section demonstrates the socioeconomic impact of successful PPPs through output-based performance leading to efficiency gains in the provision of public infrastructure assets and services. The selected success stories demonstrate that the advantages of PPPs can go beyond the cost and time efficiency during the development of the asset extending across the whole life cycle of the asset through the long-term implementation and operation process.

4.2.1.1 Transport Sector

Demand increase – Suape Container Terminal witnessed the increase in the Twenty foot Equivalent Units (TEUs) reached 500%, over 300,000 TEUs annually compared to pre-commission. This economic efficiency gain was associated with additional socioeconomic impact of increased employability of 172 job created. (IFC 2008)

Time Efficiency in Ports – Port of Toamasina in Madagascar witnessed the decrease in loading and unloading time resulted in the increase of the number of container from 10 to 30 per hour per vessel where time required for yard handling decreased from multiple days to a number of hours. (IFC 2010)

Time efficiency in Roads – Hyderabad mirpurkhas Dual Carriage Way Project in Pakistan witnessed the reduction in the travel time from 100minutes to 30 minutes. This economic efficiency gain was associated with an additional socioeconomic impact of increased employability through 15000 indirect jobs and 5000 direct jobs. (PPP unit, Sindh government 2012)

Reduced Service Fee – Virgin Samoa Airlines in Samoa witnessed the reduction of airfares that resulted in estimated savings of 57.7million USD and increased demand of 243,000 between 2005 and 2009. This economic efficiency gain was associated with an additional socioeconomic impact of increased employability through 671 jobs and improved salaries. (WBG, 2009)

4.2.1.2 Water Sector

Reduced Service Fee – Shanghai water authority witnessed the reduction of the service fee for treated waste water at CNY 0.33 per cubic meter at minimum treatment level of 1.4 million m3/day. This resulted in generating savings of 1.4 million m3/day, around 40% of the estimated government service fee. (ADB 2010)

Retained long-term Service Fee – Busembatia in Uganda witnessed the results of output-based performance management contract through retaining a fixed service fee for 5 years. This economic efficiency gain was associated with an additional socioeconomic impact of improved service reliability through 24-hrs service and extended service coverage through 430 new water connections.

4.2.2 Failure Stories in PPPs

This section demonstrates the influence of socioeconomic factors on the success and failures of PPPs. It explores both type of stakeholders, decision makers and end-users where the political support of the decision makers and affordability for end-users have been 11tilize11iz in normative literature as CSFs for the success of PPPs.

4.2.2.1 Failure due unaffordability

SR 91 Orange County (USA) – The increased toll rates were poorly received by road users who have driven elected officials to re-own it and reduce the tolls. (Fitch, 2013)

Chicago Street Parking (USA) – The very high initial tariff resulted in public outrage and escalations that led to the cancellation of the concession in the first few years. (Fitch, 2013)

4.2.2.2 Failure due to lack of political support

Stewart Airport (USA) – Major regional airports were a strong barrier due to their well-established connections despite the initial anticipation of attracting new carriers. Future demand risks require some sizeable public equity to be feasible. (Fitch, 2013)

Hospital Sud Francilien (France) – The delays and cost overruns resulted in PPP failure driven by political bias against PPPs which led to unnecessary changes delaying the overall project progress. (Fitch, 2013)

5 Conclusions and Further Research

The aim and objective of this paper was to explore the significance of incentivized output-based performance in driving efficiency gains and associated socioeconomic impact. The conducted analysis in this research based on primary data gathered from semi-structured interviews and multi-case study research, and secondary data of existing academic literature and industry report, concur the research hypothesis where incentivized output-based performance tends to maximize the economic profits of the private partner incentivizing the efficiency gains where usually a revenue-sharing mechanism and increased demand are the biggest motivations. The analysis interpreted the importance of socioeconomic parameters in the success of PPPs especially output-based performance and user-pays PPPs in addition to interpreting the socioeconomic benefits derived by efficiency gains, thus deducting the overall importance of socioeconomic parameter in the provision of public infrastructure assets and services. The research analysis provided comprehensive answers to the research questions through the research recommendation in the following section.

5.1 Research Recommendations

Recommendation (1) – In a broad term, public finance can`t suffice for the provision of public infrastructure and services neither financially due to the infrastructure finance gap nor technically due the difference in the levels of experience of the private sector compared to public sector and moreover, the strict contractual nature of PPP which allocates the risks to the party best able to manage it which succeeded to a large extent to reduce significantly cost and time overrun especially in availability PPPs.

Recommendation (2) – Incentivized output-based performance PPPs drives the private sector to achieve optimum efficiency thus maximizing the efficiency gains and the associated profits. In standard output-based performance contract, private sector is paid at fixed targets and penalized for defaults but not rewarded on exceeding targets where incentivized output-based contracts through revenue sharing or rewarding schemes, motivates the profit-driven private sector to utilize the best of its experience and innovation to maximise efficiency.

Recommendation (3) – Socioeconomic parameters in PPPs have a crucial value at both ends of PPPs. From one end, socioeconomic parameters of political support (decision maker) and affordability (end users) plays a key role in the success of PPPs especially in public sensitive sectors as healthcare, education, and aviation. On the other end, the socioeconomic benefits resulting from output-based performance PPPs and its associated efficiency gains, are significant to the socioeconomic growth and quality of life e.g. reduced service tariff, improved service quality and coverage, service reliability and availability and moreover, employability and income. Socioeconomic parameters can be considered as key performance
indicators for PPPs and should be comprehensively assessed at the initial stage of the projects similar to the cost benefit analysis undertaken by some developed countries at the screening stage of PPPs.

5.2 Research Critique and Limitations

Limited Interviews – Despite the broad sample, breadth of its background and significance of its experience in the research field, only transaction advisory experience was comprehensively investigated to the vast experience of advisors across various projects in different location. The sample should have included wider representation of each group.

Interviews Timing – Despite the comprehensive and consistent primary data extracted from the semi-structured interviews. Several interviews were conducted in conjunction with the case study research where the interpretations and insights of those the experienced practitioners might not have fully contributed in the fine-tuning process of the hypothesis.

Secondary source bias – A large portion of the secondary data are produced by international organisations and Western expats that might be affected by the western political, technical, and socioeconomic parameters through their investigations and interoperations. This research was restricted with this approach due to the lack of performance measurement data of PPPs in the Middle East through the procuring government agencies, in addition to the limitation of locally developed industry reports.

5.3 Recommendations for Future Research

Recommendation (1) – The existing literature is very limited in the critical research area of output-based performance measurement of PPPs and quantification of improved value for money. The future research is this area will contribute to the enhanced performance of PPPs.

Recommendation (2) – The socioeconomic impact of PPPs require further research work to identify the main parameters of efficiency gains that drive socioeconomic benefits, and the early assessment of socioeconomic parameters to integrate its requirements in the early stages of the project preparation and the its specifications within the project agreement in specific the relationship to support the national development agenda and the sustainable development goals (SDGs). The identification and the measurement of relevant environment, social and governance (ESG) parameters will be crucial to achieve such strategic integration.

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Strategies of urban resilience related to the built environment: an overview of the literature

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Abstract
Urban resilience has been an increasingly discussed topic in the scientific community. The term relates to the city's ability to return or simply not to interrupt its routine in the face of some disturbance. Cities around the world have sought to create and implement strategies to improve their resilience to cope with tensions arising from climate change, as well as issues that are already familiar to them, but which have not been overcome. Thus, studies on resilience run through urban systems and communities, which makes the theme attractive and necessary for the engineering context, since it is indispensable for the construction of an smart and prepared environment to face climate change. This article presents an overview of the current literature on the implementation of urban resilience strategies directly related to the built environment and the construction industry. Bibliographic research uses systematic mapping supported by bibliometric analysis and performs content analysis to identify trends and gaps in knowledge. As a result, several strategies, both governmental and technological, applied in various cities around the world are identified and categorized. In addition, the need for more studies on urban resilience in the built environment was perceived.

Keywords: Built environment, systematic mapping of literature, urban resilience.

1 Introduction

Cities are population concentration hubs with a forecast that will shelter 70% of the world's population by 2050 (United Nations 2019), a scenario that requires increasingly robust and efficient infrastructure. However, most cities already present serious problems in these contexts, such as lack of sanitation, solid waste management, households located in inappropriate places, high energy consumption, air and water pollution (Chang *et al.* 2016, Madeiros *et al.* 2018, Myers *et al.* 2021), among others.

In this sense, it is important to understand the role of the built environment in the well-being of cities. According (Sapeciay *et al.* 2017), the built environment is a consequence of the work of the construction industry combined with new technologies and governmental and private initiatives generating spaces for population day-to-day life. The pressure produced by the population increase generates the need to expand and adapt these urban spaces and infrastructures (Rees 1999) taking into account the issues of climate change and problems already faced by cities.

Additionally, the construction industry consumes a considerable part of the raw material extracted from nature, being responsible for one third of greenhouse gas emissions of the world and, in particular, carbon dioxide (CO2) (World Economic Forum 2017), having extremely relevant potential for the creation of infrastructure to adapt to climate risks such as floods and rising sea levels (Park and Won 2019). Thus, the behaviour of the construction industry to support actions for urban resilience must be evaluated. The United Nations Office for Disaster Risk Reduction (UNISDR) (2012, p. 4) puts it that "All who make a city function, from municipal service providers to urban planners to the private sector and residents themselves, must be committed to building safer cities to secure resilience," which reinforces the role of the construction industry in building urban resilience.

Urban resilience is a term still under discussion due to the different connotation that can be adopted in each study area. Ribeiro and Gonçalves (2019) point out that half of the definitions are inserted in the context of threats (floods, earthquakes, etc.) and another part are inserted in the context of urban sustainability.

In a literature review, which included several papers on the subject, Meerow et.al (2016) presents the following general definition that can be applied to multiple areas: “Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity”.

Discussions on urban resilience contribute for decision-making in several cities resulting in planning proposals called “resilience strategies”. In the city of Salvador (Brazil), for example, the resilience strategy was defined as a "proactive, integrated, collaborative, flexible, and long-term plan to address the challenges of the city and people in urban life" (Prefeitura Municipal de Salvador 2019, p. 10). In some places, this discussion is advanced and already have exclusive documents about it, as is the case of Salvador, mentioned above. In contrast, in other regions, such as Addis Ababa (Ethiopia, Africa), discussions are still evolving. There are still few studies on the subject. And it is noted that urban resilience studies developed in America and Europe do not suit the reality of their region (Baron and Cherenet 2018). It is important to observe how the development of research and application around the theme has been given and the relevance given to it in different regions.

Urban resilience is placed by Leitner et. al (2018) as a new urban development and governance agenda involving actors from all sectors generating globally applied standards and evaluation tools that make urban resilience technical and managerial. This makes resilience attractive to the private sector and integrating urban planning and governance structures. Programs such as Resilient Cities Network (https://resilientcitiesnetwork.org/), C40 (https://www.c40.org/) stand out supporting cities in developing their resilience strategies.

Research conducted in databases such as Scopus and Web of Science shows that there is a gap to be filled when it comes to studies on urban resilience in the context of the construction industry. There is a clear scarcity of work that addresses these areas simultaneously. In addition, the existing works are mostly found in Asian countries and usually encompass solutions aimed at specific contexts, making it difficult to spread their applications in other regions.

The aim of this article is to present an overview of the current literature on the implementation of urban resilience strategies directly related to the built environment and the construction industry. It seeks to identify how such studies recognize and treat urban resilience, based on the classification and analysis of the strategic actions they advocate.

It is expected that the results of this research can contribute to promote and direct the realization of studies related to the theme, especially in regions lacking such advance in knowledge.

2 Research methodology

The present study performs a systematic mapping of the literature (SML), supported by bibliometric indicators. To this end, we adopt the definition of SML indicated by Keele (2007), which says that systematic mapping consists of a broader approach to research, returning data that point to evidence groups or evidence deserts identifying areas that are performing well in their work or that need to develop more studies, respectively. The bibliometric analysis, in turn, is defined in this study as the process used to obtain quantitative data of interrelations between subjects and diverse scientific groups, obtaining an overview of the literature (Ellegaard and Wallin 2015).

The research was divided into two phases (Figure 1). In the first phase (Delimitation of publications), a choice of research terms, string formulation, choice of databases and article selection was made.

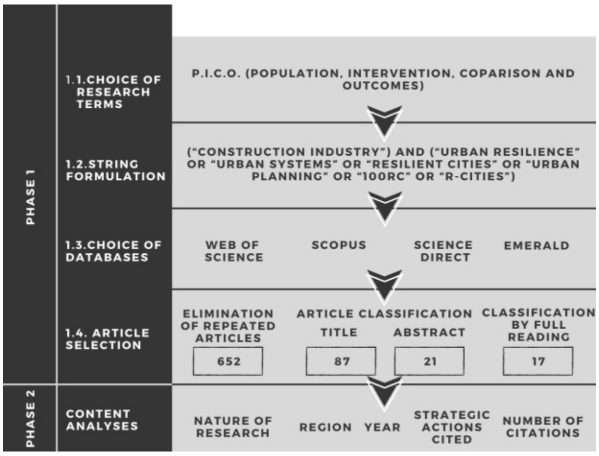

Figure 1. Research development.
Source: The authors.

The choice of search terms (Item 1.1) was made based on the adaptation of the PICO method (Population, Intervention, Comparison and Outcomes). The research terms were defined according to population, intervention, comparison and outcomes (Pai *et al.* 2004). As a result, it was defined: construction industry, urban resilience, urban systems, resilient cities, urban planning, 100RC, R-Cities. The terms were combined with Boolean operators AND and OR in order to delimit the search and gave rise to the string, as shown below: ("Construction industry") AND ("urban resilience" OR "urban systems" OR "resilient cities" OR "urban planning" OR "100RC" OR "R-Cities"). The quotation marks (" ") were used to recognize the sentence as the only term, that is, not to perform the search taking into account the words in isolation.

In the search for publications, the following databases were used: Science Direct, Web of Science, Emerald and Scopus (Item 1.3). These bases were chosen for their relevance in the dissemination of scientific production related to the built environment.

For the article selection (Item 1.4), the most relevant studies for the theme are identified. Articles that met the following criteria were selected: only articles from journals indexed in the time interval of the last 5 years and search in the title, abstract or keywords. The total return was 658 articles, 107 from the Science Direct database (16.3%), 49 from Scopus (7.4%), 384 from the Web of Science database (58.4%) and 118 from emerald base (17.9%). Then, repeated articles were removed. Six articles were excluded at this stage.

From this point, three selection processes were carried out. Initially, the first filter (Classification by title) was applied. This selection was made by reading the title of each publication and evaluating the relationship of the theme treated in the article with the research question. The second filter (Classification by abstract), the relevance of the content of the articles was evaluated by reading the abstract. Thus, only 87 of the 652 articles identified were considered relevant after reading the title. After reading the abstracts, only 21 of the 87 articles selected in the first filter were considered eligible. Finally, the third filter (Classification by full reading) was applied. At this stage, 4 articles were discarded because they presented content not related to the objective of this research. Figure 2 details the Article Selection step.

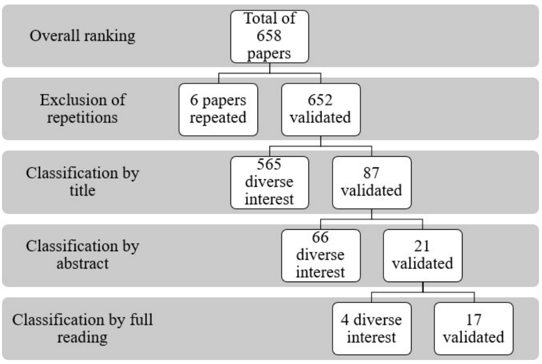

Figure 2. Article selection step.
Source: The authors.

In the second phase (Content Analysis) the results obtained in the first stage are performed. The 17 validated articles were classified by region, year of publication, number of citations, strategic actions cited and nature of research. The latter was divided into three categories: framework, case studies and literature reviews. Subsequently, the strategic actions adopted by the construction industry mentioned by the articles were evaluated, encompassing the development of models, certifications and new approaches/technologies.

3 Findings and Discussion

Figure 3 shows the classification of the selected papers by region and number of citations (A1 (Chang *et al.* 2016), A2 (Park and Won 2019), A3 (Ali *et al.* 2016), A4 (Cheshmehzangi 2021), A5 (Nelson 2016), A6 (Hatvani-Kovacs *et al.* 2018), A7 (Maund *et al.* 2018), A8 (Murtagh *et al.* 2020), A9 (Ciccaglione 2019), A10 (Bignami 2017), A11 (Göswein *et al.* 2021), A12 (Clarke *et al.* 2020), A13 (Myers *et al.* 2021), A14 (Baron and Cherenet 2018), A15 (Yaman Galantini and Tezer 2018), A16 (González *et al.* 2020), A17 (Paiva and Schicchi 2020)). It is observed that the publications are distributed as follows: Asia (24%), North America (6%), Europe (24%), Oceania (12%), Africa (18%), Euro-Asia (6%) and South America (12%). When relating this information with the number of citations of the published articles, it is observed, however, that Asia stands out with 63 citations (60%), followed by North America with 22 (21%). Oceania presents 10 citations (10%), Europe five (5%), Africa three (3%) and Euro-Asian region two (2%).

Figure 3 also shows the relationship of this information with the year in which the publications were made. It is observed that 2018 and 2020 are the years that had the most publications.

Asia stands out with the number of citations because of the article A1 entitled "Facilitating the transition to sustainable construction: China's policies" (Chang *et al.* 2016). A1 also stands out for being the most cited article among all selected ones. This research, in particular, investigates the political system in China, which has released several laws, regulations and policies in order to facilitate the transition to sustainable construction.

The South American region, in turn, presents only two articles: A16, entitled "Urban flood resilience in Chile: San Fernando and Los Ángeles experiences" (González *et al.* 2020), and A17, entitled "Regeneration and Resilience: Recent Urban Interventions at Roosevelt Square in São Paulo" (Paiva and Schicchi 2020). These articles are characterized by not being mentioned at all, by being recent (both are from 2021 and 2020, respectively) and by presenting case studies that report specific situations of each region.

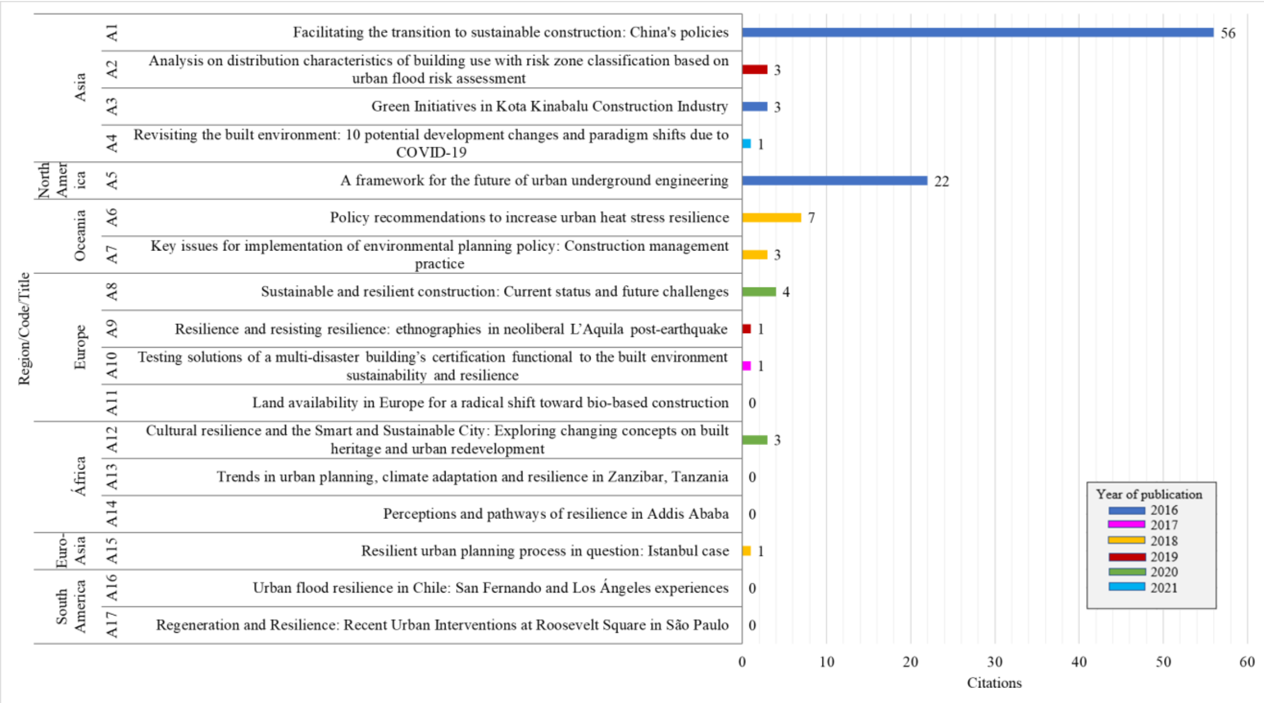

Figure 3. Region x Year x Number of citations x region
Source: The authors.

The articles were also evaluated according to the research methodology adopted (Figure 4). After analysis of the sample, it was possible to classify the surveys into three categories:

- Framework: in this category, the research that proposed to develop /present a framework on the subject of this article were classified. In this case, a framework is defined as a conceptual structure (Munck et al. 2013) based on the relations of dependence between paradigms, attributes and practices on some subject (Santos 2012).

- Case study: in this category, the studies that proposed to conduct a case study on the object theme of this article were classified. For that, it was adopted the definition of case study indicated by Noor (2008). The author indicates that a case study is an investigation of a given subject, characteristic or unit of analysis on how and why it happens in a certain way, allowing the evaluating of the differences between what was planned and what occurred.

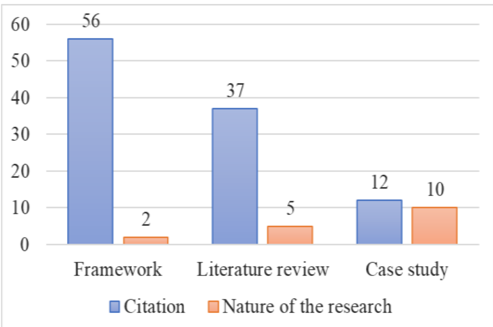

Figure 4. Number of articles by research nature x Number of citations by research nature.
Source: The authors.

- Literature review: in this category, the studies that proposed to conduct a systematic review of the literature were classified. For that, a literature review is defined as a "summary of a subject field that supports the identification of specific research questions" giving direction to future research, in addition to providing research propositions and methodologies (Rowley and Slack 2004, p. 31).

Most of the selected articles (59%) were classified as case studies that have a local approach. It is also observed that some studies do not have a replicable character. However, in some cases the results obtained point to the possibility of expanding the knowledge acquired to other regions, such as the article A16 (González *et al.* 2020).

The studies that showed the lowest number of citations were classified as case studies (Figure 4). However, when analyzing the year of publication of articles, this trend is justified, since most of the studies listed as a case study are more recent.

From the detailed reading of the articles, it was also possible to identify and classify strategic actions that involve the construction industry and have the potential to improve urban resilience. Such actions are addressed directly or indirectly by the selected literature. A total of 47 actions were identified, which could be classified into three categories, described below:

- Model development: This category classified the actions related to the development / implementation of quantitative, qualitative and management models applicable in a given subject.

- Certification: This category classified the actions that proposes to develop / implement certifications that seek to measure the performance of a particular technology or structure as a whole. A certification covers specific criteria for each type of product and establishes a ranking according to how much the product fits the established criteria adding value to the object of study (Devine and Kok 2015).

- New approaches/technologies: This category classified actions that promote the use of research results, propose suggestions of what still needs to be done, and / or encourage the development or improvement of technologies.

Figure 5 shows the relationship of these categories with the research methodologies adopted in the selected articles. It is possible to observe that the studies classified as case studies do not present a relevant number of actions, even though this category represents the major amount of publications analysed. The largest number of actions can be found in the literature review articles, where it was possible to identify 18 linked actions (38% of the total strategic actions identified). As expected, since a literature review study brings together placements of several studies, thus addressing several solutions.

It is also observed that most of the actions identified are classified as actions related to new approaches / technologies. All suggested actions could be viewed in more detail in Table 1. This table presents the strategic actions identified by type and by region.

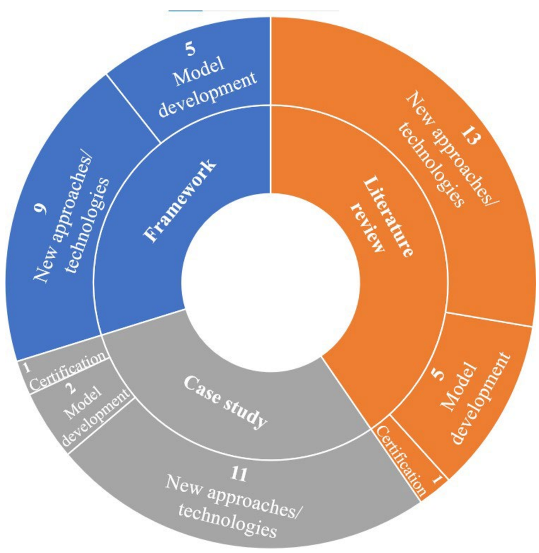

Figure 5. Methodology x Types of actions x Actions.
Source: The authors.

The model development actions mostly seek to measure the resistance of structures to disturbances, in order to design more efficient structures, in addition to, from these models, determining the types of technologies and management models that best suit specific situations. This category has as strong allied technological tools for the creation and validation of methods and models. It also includes actions involving structural, architectural and governance changes.

Table 1. Actions identified in selected articles

Region		Actions	Model development	Certification	New approaches/technologies
North America	1	Performance Response Function (PRF) analysis	X		
	2	Engineers need to learn how to engage and communica with social scientists and planners.			X
	3	Develop cyber-environments	X		
	4	To develop functional computational models	X		
	5	To develop the information for model validation	X		
	6	Establish a market for underground space			X
	7	Develop life cycle decision models	X		
	8	Be aware of new technologies			X
Oceania	9	Guidelines to heat stress resistant building design			X
	10	Financially incentive heat stress resistant design			X
	11	Showcase heat stress resistance public buildings	X		
	12	Integrate heat stress resistance into the Australian National Construction Code (NCC)	X		
	13	Implement Building Energy Performance Certification (EPC)		X	
	14	Address non-compliance issues			X
	15	Create or review policies with clear and objective goals			X
	16	Improve communication and coordination between government and non-governmental sectors			X
	17	Improve collaborative and professional partnerships to advance the implementation of activities			X
Europe	18	Invigorated research focus on how construction can ada the built environment to the altered future due to climate change			X
	19	Provide legal framework to application of bio-based materials			X
	20	Ensure that reconstruction is not evaluated as a resilienc action without taking into account other variables			X
	21	Certification Tool for Disaster Resistance Predisposition of Buildings (CePRED)		X	
Asia	22	Decline in car-based transportation infrastructure			X
	23	A push for information-based construction management methods	X		
	24	Increase in off-site construction and engineering			X
	25	Increase in lightweight structural systems	X		
	26	Revisions in density and compact design	X		
	27	Spatial planning considerations			X
	28	Smaller and individual internal layouts			X
	29	A push for meso scale strategies at the neighborhood/community level			X
	30	New opportunities for non-centralized building systems			X
	31	Method to enable advance prevention and reduce flood damage by establishing a measure for land utilization and building by using quantitative data i terms of urban planning, a nonstructural measure.	X		
	32	Awareness, education and training on green technologies			X
	33	Consider social and economic factors in policy making			X
	34	Detailed policies to improve the public participatio in the environmental impact assessment process of			X
South America	35	Flood resilience assessment model that can be exported to other cities and other countries	X		
	36	Analyze and understand the physical and social impact of policies for intervention in local public			X
Africa	37	An integrated strategic, social, environmental, and climate assessment of major development infrastructure plans should be made mandatory to a socio-economic and industrial sectors.			X
	38	Improving capacity building for coping and adapti is essential			X
	39	Reuse of extant buildings			X
	40	Ecosystemic driven perspectives on the built environment that engender growth through adaptiv change as alternative to disruptive demolition and new build practices			X
	41	Advancing governance that foster cultural resilienc especially in relation to land use, planning and acc to heritage			X
	42	Potential role of heritage as a regenerative urban force in culture-conscious urban strategies, specifically relating to community, identity, contestation and appropriation			X
	43	Engendering inclusion through generative commur based design processes			X
	44	Material preservation and restoration approaches founded in both skills-based and high-tech technologies			X
	45	Much more research needs to be done outside Europe or America to make urban resilience a truly global movement.			X
Euro-Asia	46	Revise a conventional allocation of land for housin roads, tourist resorts and settlements in favor of a more efficient and smart climate strategy that does not marginalize the economically disadvantaged.			X
	47	Collecting experiences and ideas contributing positively to the planning process through creativit and innovative policies.			X

Source: The authors.

The certification category is the result of research and case studies. This information is synthesized and structured in a tool that allows you to measure the performance of a construction on the subject covered by it. The certifications, placed here as actions, deal with measuring the energy performance of a building and measuring the predisposition to resilience to disasters. It is worth mentioning the Certification Tool for Disaster Resistance Predisposition of Buildings (CePRED) (Bignami 2017). The author signals that it can become a tool for resilience measurement that is something much broader than the initial proposal put by him. Studies around certification continue to be improved with this objective.

Considering the new approaches/technologies category, governance actions stand out bringing suggestions for new policies and revision of existing ones. The actions of direct intervention in the design and construction of structures are also highlighted, suggesting the use of new materials, technologies and approaches. Cheshmehzangi (2021), author of the paper A4, entitled "Revisiting the built environment: 10 potential development changes and paradigm shifts due to COVID-19", makes a place on the trend of reducing workspaces in public buildings, commercial buildings, offices and the like, due to the new reality imposed by the pandemic, where the number of people in these physical spaces has decreased considerably. The category also addresses actions on choking between the community and those responsible for decision-making (government, private sector and engineering professionals), research and qualification of the professionals involved. It is noteworthy that engagement and communication between the various spheres is a gap pointed out by some of the works. These works highlighted the need of communication with communities, since they enjoy the benefits and disadvantages to which cities are exposed.

When assessing actions by region, it is noted that Euro-Asia and Oceania have a greater focus on government policies, but in Oceania interventions in building projects with heat stress also stand out. The North American region has a greater focus on technical advancement. Europe has a greater focus on adapting the built environment to climate change by implementing bio-based materials and measuring the resilience of buildings to disasters. The Asia focuses on improving construction productivity by adopting new construction and management techniques, new ways of designing spaces in the face of the pandemic scenario, in addition to making the user an active part of the process rather than just spectator. In South America, the approach is more focused on the development of a flood resilience assessment model and the physical and social impacts that interventions on public spaces cause. In Africa it tends to take social issues more into account in decision-making and the use of existing structures, as well as reinforcing the need for more research on urban resilience that appropriates its reality. Some issues are highlighted, such as the reuse of existing structures, cited both in the Africa region and in Europe, which can and should be taken into account elsewhere. In addition, the search for the engagement of society as a whole in decision making, as it was put by Africa, South America, Euro-Asia and Asia and the implementation of new technologies, as perceived in North America.

4 Conclusions and Further Research

The SML tool initially returned a significant sample of papers published in the last five years. However, when the selection criteria were applied, the sample was reduced to 17 articles that effectively involve the concept of resilience and built environment. This sampling, obtained through the aforementioned method, reveals that there is still much to be done in the context of the construction industry addressing strategies that make urban environments more resilient. This sector plays an important role in adapting to climate risks, since consumes large amounts of insum, generates a lot of waste and, moreover, the products generated by it continue to consume natural goods. This reinforces the need for the sector to be thought of with greater discretion.

By categorizing strategic actions of urban resilience adopted by the construction industry, it was noticed that a pattern of innovation and governance tools, showing that the innovation movement of the sector is evolving. In contrast, it is also necessary that these changes receive support from government policies, and are accompanied by professional training programs for the sector. For changes to actually happen, it is necessary to establish dialogue between all the authors involved, government authorities, the community and professionals in the construction industry and other areas of knowledge. The engagement between professionals from diverse knowledge areas and engineers is pointed out as a difficulty for engineering professionals (Nelson 2016).

The results also point to the need to investigate urban resilience in different regions, since the strategies applied in a given place may not apply in the other regions. The regions of Asia, South America, Euro-Asia and Africa have shown an approach that takes more account of the social aspect and role of the construction industry in this context, while North America, Europe and Oceania are more focused on government policies and technological and constructive advances. Thus, as a suggestion for future work, an investigation could be made in specific regions, aiming to evaluate with has the interrelationship between urban resilience and built environment.

Finally, it is worth noting that this study is restricted to the results obtained from the search string and the databases adopted. The sample analysed does not necessarily include the entire state of existing knowledge related to the subject but analyses a representative sample of articles on the subject.

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Challenges to the Adoption of Strategies and Regulations for Energy Efficiency Initiatives in the Retrofitting of Retail Centers

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Abstract
This study investigates the challenges experienced in the implementation of energy efficiency retrofit initiatives in retail centres in South Africa. The participants of the study were management of 20 retail centres in and around the KwaZulu-Natal province. A close- ended questionnaire was used to determine to examine the challenges associated with implementation. The stratified random sampling was used to determine the sample of the population to be used. Data was analysed using descriptive statistics comprising of frequency distributions providing the mean, median, standard deviations as well as maximum and minimum values for nominal data. The findings of the study indicated that the issues faced by retailers were the high capital costs as well as lack of demand from tenants and customers. Larger retail centres who have overcome these challenges enjoy the many benefits associated with the implementation of retrofit energy efficiency solutions. Further study into the level of benefits received through various implementations of retrofit solutions could provide a detailed mapping of implementation solutions with relation to benefits achieved. Challenges faced by retailers could be extended to challenges faces by building or property owners as well as store managers. Limited reasons were investigated in this study for lack of implementation of energy efficiency strategies. Further study can be done into more reasons for lack of implementation. Many retailers declined to provide information surrounding the cost of strategies implemented and benefits received, more study can be done surrounding the costs of energy implementation.

Keywords
Energy Efficiency, Retrofit Strategies, Green Buildings, Retail Centres

1 Introduction

Energy management has become a key part of organisational life across all industries (Christina et al, 2015). The demand for energy far exceeds the available supply of energy in most countries (Hedden and Hedden, 2015; Lecca, 2014). This has been attributed to the fact that more than 50% of the world's population lives in an urban environment and it is expected to increase to 70% by 2050 (Lecca, 2014). This demand forces consumers to consider how much energy they consume and possibly integrate between various forms of supply and demand side resources (Golove et al, 1996).

South Africa is an energy-intensive country, with mostly coal-generated energy (du Plessis, 2014). The country is one of the largest coal producers in the world, and yet it is short of electricity (Bullock, 2011). In 1998, the White Paper on Energy Policy stated that "by 2007, all current electricity sources in South Africa will be fully utilized" (DME, 1998, page 41). In 2008, energy demand exceeded the supply of energy to the country and rolling blackouts known as load-shedding began (Bullock, 2011). Rolling blackouts are scheduled downtime of electricity for either a scheduled or unscheduled period in an area. This is disruptive for the industry and is expensive to recover losses. Continued rolling blackouts have made consumers more aware of the finite amounts of energy available in the country and has started a trend towards a more optimal use of energy. The use of energy efficiently will contribute significantly in stabilising the country's energy crisis (du Plessis, 2014) by 2030.

Buildings, both residential and commercial have been found to consume between 20- 40% of total final energy consumption (Perez-Lombard et al., 2008). The move from old inefficient structures to more energy efficient buildings has become a growing initiative globally. The public and private sectors in South Africa as well as many other countries have implemented several initiatives, legislation, and voluntary mechanisms such as green building rating systems for new buildings. Due to these initiatives, several new residential, commercial, and industrial developments have implemented these strategies resulting in reasonable energy savings in South Africa (Eskom, 2012). However, the implementation of energy efficiency must be undertaken as a strategic measure to advance sustainable development of the entire built environment. Sustainable development is not only important when looking at new buildings but is imperative to further provide ad-hoc plans and measures to improve the environmental quality and reduce the energy consumption of existing buildings, which in essence represents a much larger percentage of the built environment (Eskom, 2012).

In 2009, the Department of Minerals and Energy (DME) in South Africa released the revised National Energy Efficiency Strategy which proposed an overall 12% reduction in energy demand by 2015 across all sectors. The commercial sector had the highest expected demand reduction at 20%. However, in 2013 the strategy was abandoned due to the targets being no longer achievable (du Can et al, 2014).
The South African government in late 2011 published the SANS 10400 XA that obliges all new and majorly retrofitted buildings to comply with the new energy efficiency requirements stated in the code. The conversion of existing buildings to green buildings is beginning to become a need, more than an optional trend in South Africa. In the last 6 years, 50% more firms in South Africa worked on green building projects and more than half of these projects were retrofit projects (Okorafor, 2019). As load- shedding became a part of South Africans daily routine, more businesses and individuals look for alternative sources to save energy at lower costs, the use of green technology has become a more attractive option for many (Hedden, 2015).

The commercial sector in South Africa utilizes 10 to 15 % of total energy consumed in the country (Eskom, 2014). According to ESKOM's usage data, the commercial sector in South Africa is seen to have a constant daily usage of energy, irrespective of season or day of the week (Eskom, 2014). This implies that a small change in energy usage, applied over a daily period would yield a significant saving. This could be done through a number of energy retrofit options. Energy retrofit is in fact the preservation and refurbishment of buildings and their continued operation using energy efficient technologies and practises (Zhivov, 2015). The primary value this adds to a building is the reduction of operating costs as well as their adverse environmental impact. Another aspect closely related to energy retrofit is Energy Management, which has also become a key aspect across all industries which is proving to have an increasing interest in response to achieving desired carbon emission targets (DEFRA, 2006). Previous studies observed that low to medium cost interventions might bring energy savings of 25% or more for this sector (Reynolds, 2007). The need for further research and data that can foster the implementation of strategies for improving energy efficiency in existing commercial buildings has therefore become evident in South Africa.

Among commercial buildings, the retail sector and particularly shopping malls play a significant role for global energy consumption in the country. This is due to the high levels of energy consumed by these types of buildings. The trend towards density of the retail spaces into shopping malls is increasing and South Africa has the 6th highest number of shopping malls in the world (Mason et al., 2019). The retail sector offers a great potential for energy savings as retail stores have many similarities, and strategies can be implemented across all stores. If energy retrofit is implemented as a combination of awareness, technology, social behavioural patterns, as well as managerial initiatives, it might lead to truly efficient retail retrofit (Langner, 2013).

This study will therefore investigate the possible challenges to the implementation of retrofit energy efficient strategies for existing commercial retail buildings in South Africa.

2 Literature Review

2.1 Retrofit in commercial buildings and commercial retail buildings

The negative impacts of commercial retail buildings on the environment include natural resources use, material use, energy consumption, greenhouse gas emission and waste. With the growing world population and rapid economic growth (26% over 2017/2018 period), the demand for high performance 'green' or sustainable buildings is becoming increasingly important in the retail industry (Dangana, et al., 2012). Commercial buildings in European Union countries are responsible for significant consumption of energy which is used mainly for heating, cooling and lighting. Due to real estate being a commodity that is seldom renewed, current trends suggest the retrofit of old structures to improve the energy efficiency. Architectural renovation allows the improvement of building envelopes and energy supply systems (Aste and Pero, 2012).

In South Africa, several commercial retail retrofits can be found. Firstly, the Victoria Wharf at Cape Town's V&A Waterfront. The shopping complex is approximately 47 000m2 and comprises of about 400 retailers. The operations manager at the mall, in the timeframe of 2009 – 2012 invested 22 million in making the mall more energy efficient. He stated the reason for the change was due to two main reasons, one was for financial gains and the second was the influence of consumer expectations. They upgraded chillers and their HVAC systems. They further implemented more energy efficient escalators as well as their irrigation systems. These few changes saved the mall enough energy to power 80 000 homes for 1 month (Earthworks Magazine, 2012).

In 2009, an upmarket shopping mall in Johannesburg, Sandton City, was described as a 'thinking city', a complex thriving on socioeconomic complex with a conscience. This came about as Sandton City was rapidly growing and many expected energy usage for the area to increase drastically. Centre Manager of Sandton City at the time had responded to the statement as follows: "Despite the increases in size, capacity and traffic, we are using less electricity now than we were five years ago, this is due to a carefully planned energy conservation policy" (Nisbet, 2009).

A study done within the retail sector has recognised the potential for a sustainable transformation. Evidence from the study suggests that retail outlets that provide fresh air, natural light and have water and energy efficient solutions in place attract more customers, generate greater sales and retain more productive staff (Jordan, 2013). Nicola Douglas, CEO of the Green Building Council of South Africa, said case studies done in other countries have shown that by and large, tenants prefer green buildings which generally have more natural light, more fresh air and less 'sick building syndrome', it helps firms increase staff productivity by up to 15%, thanks to fewer sick days and for this reason tenants are prepared to pay premium rentals for a green building" (Nisbet, 2009).

Recently, a large and prominent property developer in South Africa, Growthpoint, also decided to contribute to energy efficiency. Growthpoint has a large number of commercial as well as residential buildings in their portfolio. They invested 40 million Rand in the conversion of inefficient lighting to energy efficient lighting in all 157 of their properties. This investment has benefited the electricity grid by decreasing their use of energy by 591 Megawatts (23 million units of electricity) by one property developer alone (Lux Review, 2014).

2.2 Barriers and Challenges to Retrofitting

Barriers faced in the implementation of green building initiatives have been found to range from high initial costs, lack of trained professionals, lack of demand, lack of political support, lack of awareness as well as affordability (Golove and Eto, 1996; Smart Market Report, 2018).

European Retail Forum (2009) highlighted barriers to the adoption of retrofitting as the lack of sufficient incentives or rewards for the implementation of energy efficiency. There also seem to be some conflicts surrounding the payment of the incentive. An excessive amount of administration for constructional changes, making procedures long, tiresome and time consuming was shown to discourage implementation. Nicol (2007) identified a barrier known as the Property Sector Barrier in South Africa. Each sector has its own set of barriers with regards to the implementation of initiatives. The commercial sector is no different. The reality is that most commercial buildings have tenants, and the implementation of initiatives require the co-operation of the tenant and in most cases, also involves facility managers and property managers which add to the complication. This makes implementation more costly and challenging (Nicol, 2007).

Granade et al. (2010) categorized challenges of implementation into 3 subcategories namely, structural, behavioural and availability. Structural barriers include the split of incentives between parties, the owner expecting to leave before payback period as well as incidental costs and various taxes (Dangana et al.,2012). Behavioural barriers include the risk and uncertainty faced when implementing energy efficiency strategies, the lack of awareness of information along with the practises which prevent the savings being captured. Availability barriers include the combination of efficiency saving and costly options, limited capital, and product availability as well as lack of proper installers and operators (Kasai and Jabbour, 2014). These barriers were overcome through four main solutions; namely information and education – which sought to increase awareness and knowledge surrounding energy use and options available, secondly, the use of incentives and financing – these options included grant availability for implementation and tiered pricing structures for efficient solutions (ClimateWorks Australia, 2011; Kasai and Jabbour, 2014). The third solution offered was the use of codes and standards which formed a mandate to increase the use of energy efficient options. The last option available to overcome the challenges faced when implementing energy efficiency strategies in the involvement of a third party. This required the involvement of a private company, utility, or governmental agency to support the users measures to use energy efficiency strategies.

3 Research Methodology

The quantitative research method was adopted for this study. Probability sampling was used under which, stratified random sampling was used to determine the sample of the population to be used. There are over 1400 retail centres in South Africa with approximately 180 retail centres in KwaZulu-Natal of South Africa Within these 180 retail centres the population size of the sample of 96 retail centres falls within a 100km radius of the CBD of Durban area.

Using a normal distribution curve, a confidence interval level of 90% and marginal error of 10%, the sample size was calculated to be 40. Thirty questionnaires were sent out via email or hand delivered, however only 20 completed questionnaire responses were received, representing a response rate of 50%. The expected response rate for email (postal) questionnaires is between 25%-35% (Fellows and Liu, 1997).

A Five-point Likert scale was used to rank the perceptions of respondents on the challenges that they experienced in the implementation of energy retrofit options in the commercial retail sector. To ensure the reliability of this study, the Cronbach's coefficient alpha was used to test the consistency of the obtained. All constructs had reliability coefficients greater than 0.80 indicating good internal consistency. Descriptive statistics were used to analyse the data obtained. Factor analysis was calculated along with the mean and standard deviation for each construct containing scale data.

4 Findings and Discussion

4.1 Profile of Respondents

The designation of the respondents is shown in Table 1. It is evident that 80% of the participants were Facility Managers. A Facility Manager is a professional focused on the efficient and effective delivery of support services to the organization it serves. A facility manager should be able to coordinate the demand and supply of facilities and services within the organization on a private and public level.

Property Manager is a professional charged with operating a real estate property for a fee when the owner is unable to personally attend to details. Centre Manager oversees the daily activities of a centre. The centre manager would be responsible for the security as well as financial and operational matters that arise during the daily occurrences at a centre.

Table 1. Demographic Statistics

Designation	**No**	**%**
Facility Manager	16	80
Property Manager	3	15
Centre Manager	1	5

From Table 2 it is evident that there was a median of 81 stores per retail centre ranging from a minimum of 14 to a maximum of 460 stores per centre. It is also evident that the median age of the retail stores in the sample was 19 years ranging from a minimum age of 1-year old to a maximum age of 60 years old.

Table 2. Number of stores and age of retail centres

	Median	**Minimum**	**Maximum**
Stores in the retail centre	81.00	14.00	460.00
Age of retail centre	19	1	60

4.2 Implementation of Energy Efficiency Initiatives

Participants were presented with 11 energy efficiency strategies and requested to indicate which of these strategies were implemented in their centres using a 5-point Likert scale of agreement where 1

= strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. Their responses ranked by the mean scores shown in Table 3.

Table 3. Implementation of energy efficiency strategies

Energy Efficient Strategy	**Mean**	**SD**	**Rank**
Artificial Lighting System	4.00	1.03	1
HVAC System	4.00	1.30	2
The facility management of this mall implements energy efficiently solutions	3.90	1.29	3
Energy efficiency solutions have been purposely implemented throughout maintenance	3.85	1.27	4
Implementation of Natural Lighting through more windows/doors	3.85	1.42	5
Energy efficiency solutions have been purposely implemented through interventions	3.60	1.39	6
Refrigeration System	3.35	1.27	7
Building fabric (thermal insulation)	3.35	1.27	8
Building Envelope	3.30	1.13	9
Glazing/double glazing	3.25	1.29	10
Water heating System	2.55	1.23	11

The findings in Table 4 show that respondents had high levels of agreement about the implementation of 8 out of 11 energy efficiency strategies with a mean range of 4.00 – 3.35. Participants agreed the most important strategy being implemented is the use of efficient artificial lighting systems and the use of efficient HVAC systems (mean = 4.00). They also highly agreed about the implementation of natural lighting as well as implementing strategies through a maintenance process (mean = 3.85) as opposed to implementing strategies purposely or through an intervention (mean = 3.60). Implementing strategies with relation to the building envelope (mean = 3.30) and glazing / double glazing (mean = 3.25) had medium level of importance. A strategy that is seldom implemented and a strategy that ranked lowest with medium level of importance by mean 2.55 is the implementation of a water heating system.

According to several studies that have implemented basic to advanced strategies, the starting point for any retrofit is the change in lighting systems as well as the implementation of natural lighting and upgrade or maintenance of the HVAC system. For a shopping mall there is very limited use of hot water, therefore the reason for low implementation of water heating systems as well as the medium importance level can be attributed to the minimal requirements of hot water in a retail centre.

The implementation levels of various retrofit options available for each energy intensive system; and as shopping malls move toward energy efficiency, there are currently varying levels of implementation of energy efficiency strategies. This is seen through the wide range of implementation costs across number of stores as well as through the value of implementation at various retail centres. In South Africa, initiatives by ESKOM, Pick ‘n Pay as well as Growthpoint have all made basic implementation changes in their operations to become more energy efficient.

Implementation of energy efficiency strategies in a retail centre cannot be made by a single person. Investigation, cost benefit analysis as well as an implementation strategy must be put in place to ensure maximum benefit for maximum people with minimum cost. Through the study, it has been shown that South Africa competes globally in the implementation costs and pay back periods for implementation of energy efficiency strategies.

4.3 Challenges Faced in the Implementation of Energy Efficiency Strategies

Participants were presented with 7 possible challenges faced during the implementation of energy efficiency strategies within their retail centres and were requested to indicate their level of agreement using a 5-point Likert scale of agreement where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. Their responses were ranked by mean scores as shown in Table 4.

Table 4. Challenges faced during the implementation of energy efficiency strategies

Challenges	**Mean**	**Standard Deviation**	**Agreement Level**	**Rank**
High initial costs	4.40	1.31	High	1
Lack of awareness	3.65	1.18	High	2
Lack of governmental support	3.60	1.27	High	3
Lack of market demand	3.40	1.05	High	4
Lack of trained installers	3.30	1.34	Medium	5
Lack of professional advice	3.20	1.32	Medium	6
Lack of competent professionals / consultants on energy efficiency strategies	3.20	1.36	Medium	7

The findings in Table 4 show that participants reported a high level of agreement with 4 of the 7 challenges faced during the implementation of energy efficiency strategies (mean 4.40 – 3.20). The highest-ranking response is the high initial costs faced when trying to implement energy efficient strategies (mean = 4.40). Following high initial costs was the lack of awareness around the topic of energy efficiency (mean = 3.65), lack of governmental support and initiatives (mean = 3.60), as well as the lack of demand from the market (mean = 3.40). The last remaining challenges ranked with medium awareness was the lack of trained professionals (mean = 3.30) to install energy efficient solutions (mean = 3.20) along with the lack of advice (mean = 3.20) as well as lack of competent consultants of energy efficient products and services (mean = 3.20).

It is useful to note that the items that were highly ranked are supported by the reasoning provided by the lower ranked items – for instance, the lack of professionals and installers contribute to the lack of awareness around the implementation of energy efficiency thereby creating a cycle of challenges that are harder to resolve.

The highest barriers faced in the implementation of green and energy efficiency strategies is the higher initial cost, lack of support from governmental states as well as the lack of awareness of the public in the demand for the implementation of green and energy efficiency strategies. These challenges were found in this study to be true.

5 Conclusions and Further Research

The study found that implementation of energy efficiency strategies is a growing phenomenon, with many retail centres currently implementing strategies, and many implementing strategies in stages. One of the most critical factors that affect the implementation of energy efficiency strategies in retail centres is the high initial costs of implementation. Global studies as well as this study show that the greatest barrier faced in the implementation of energy efficiency strategies is the high costs. Other factors include the lack of incentives from government as well as lack of awareness and support from professionals in the industry.

The aim of the study was further to promote the implementation of energy efficiency and create awareness of rating tools and legislation locally. This study is limited to one aspect of green buildings, namely energy efficiency. Implementation of the many green strategies available to local retail centres is a topic that can be further explored in many aspects. The findings of this study do not represent the entire Kwa-Zulu Natal province. However, they do represent the wide range of strategies that are being implemented at many levels in different retail centres at different costs and by different levels of management. This variance creates many avenues to be discussed and explored as electricity in South Africa becomes expensive and unreliable as demand grows daily.

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